ISSCC 2016

SESSION 1
Plenary

Moore's Law: A Path Forward

Bill Holt
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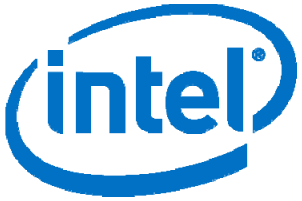


ISSCC 1986:
A 65 ns CMOS 1Mb DRAM

[See page 366 for Figure 2.]

SESSION XIX: DYNAMIC RAMs

FAM 19.2: A 65 ns CMOS 1Mb DRAM

Clair Webb, Robert Creek, William Holt, Glenn King, Ian Young

Intel Corp.

Hillsboro, OR

MANY APPROACHES have been tried in the design of a one megabit DRAM. Some using trench capacitors[1] or three dimensional capacitors[2] to achieve very small die sizes require a complex technology. Others have used simpler processes but have large die sizes.[3] This paper will describe a device that uses a planar one transistor cell design with optimized technology to achieve a die size of 50.8mm^2.

The memory cell used is a scaled version of the standard one transistor cell. The process used maximizes the storage capacitance by reducing the area needed for the isolation and contacts, allowing a 28.5μ^2 cell with 8.5μ^2 storage area as shown in Figure 1. The isolation spacing is reduced by a process that gives a bird's beak of less than 0.2μ. The area needed for the bit-line contact is made very small by

transistors M14, M24, M21, and M15 are biased at just below $V_{cc} - |VTP|$. Transistors M21 or M24 are turned off by small movements of the MIO lines. This allows M6 or M7 to pull the VVR or VVL lines low. The gain of this circuit is 35 and the delay through the circuit is about 5ns.

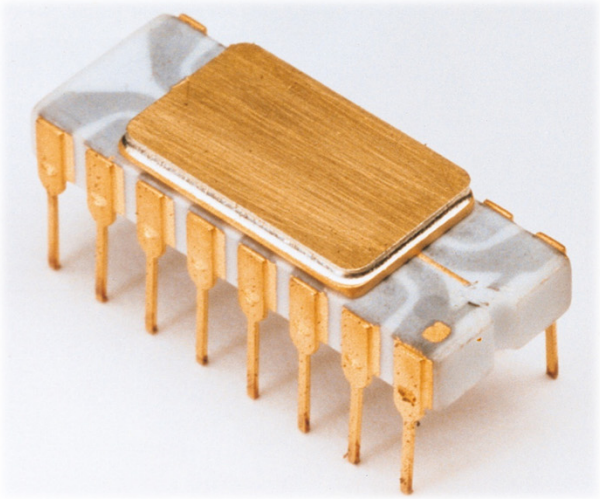
At typical processing and operating conditions the device has a 65ns row access time and 20ns TCAA as shown in Figure 5. The wide operating margins are illustrated in the shmoo plot of V_{DD} versus refresh time at 70°C shown in Figure 6. The device uses less than 100μA standby current at worst case operating conditions and less than 50μA at typical conditions. Table 1 summarizes the key performance and process parameters.

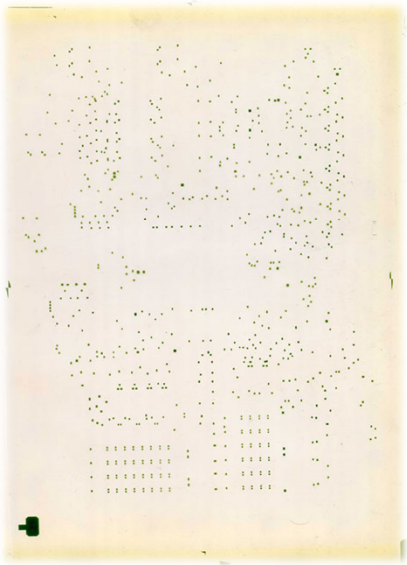
Moore's Law: A Path Going Forward

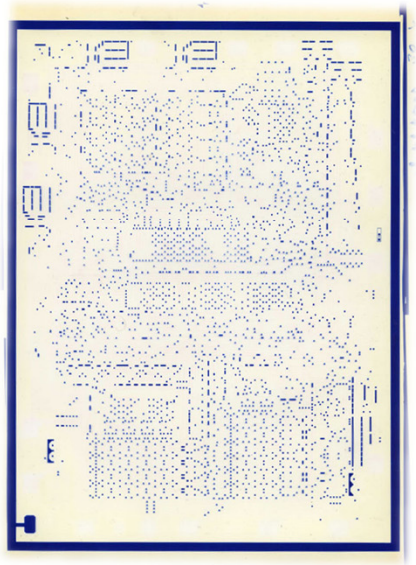
- Moore's Law
  - Economics
  - Scaling
  - Performance
- Technology Transitions
  - Enabled the Past
  - Essential to the Future
- Challenges
  - Adapting to Change

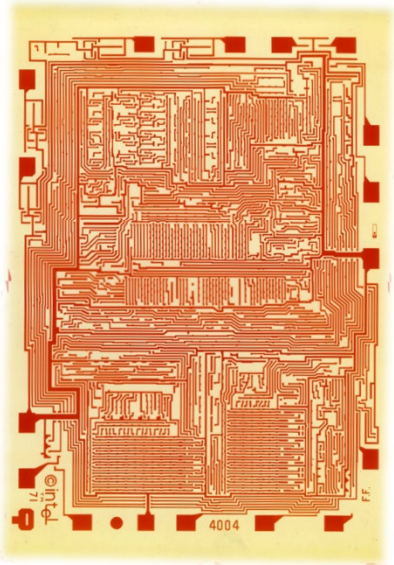
Life Was So Simple

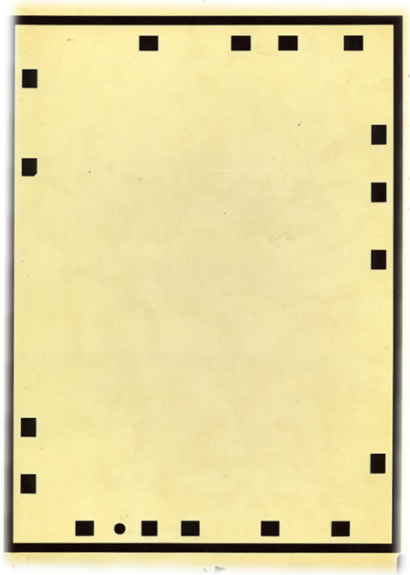
4004: 1971







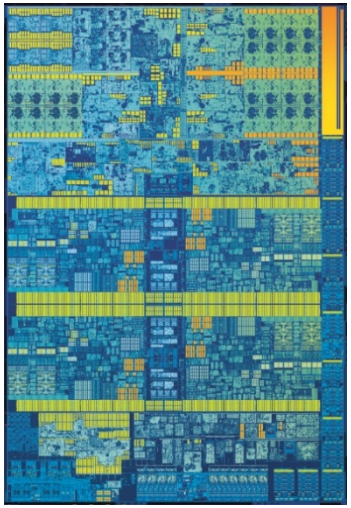




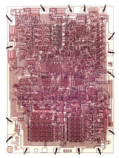
Source: Intel

Decades of Progress

6th Generation Intel® Core™ processor



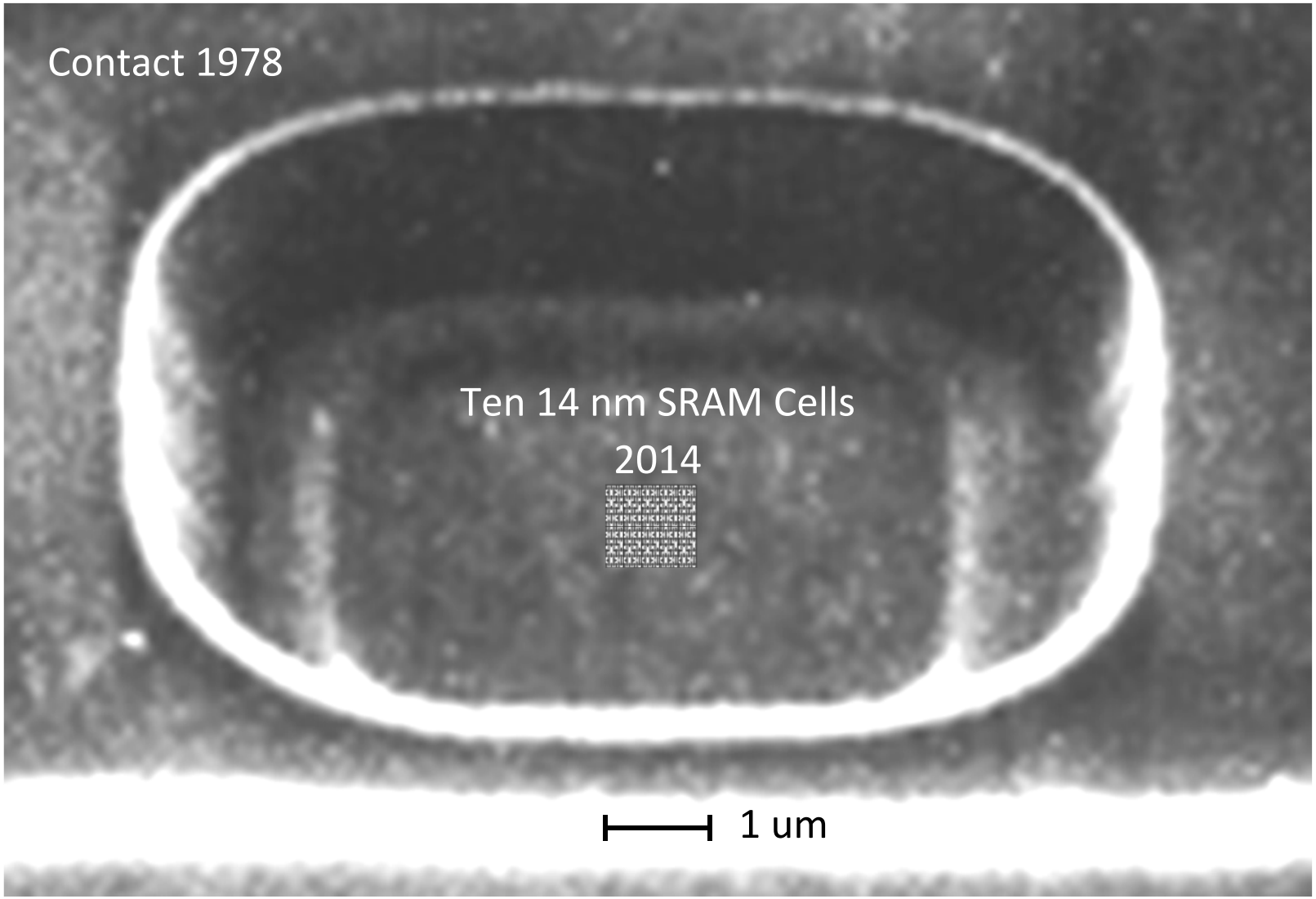
Intel 4004 processor



Processor		4004 to 14nm
Wafer size	↑	36x area
Technology node	↓	700x
Performance	↑	3,500x
Price per transistor	↓	~60,000x
Transistor Energy Efficiency	↑	90,000x

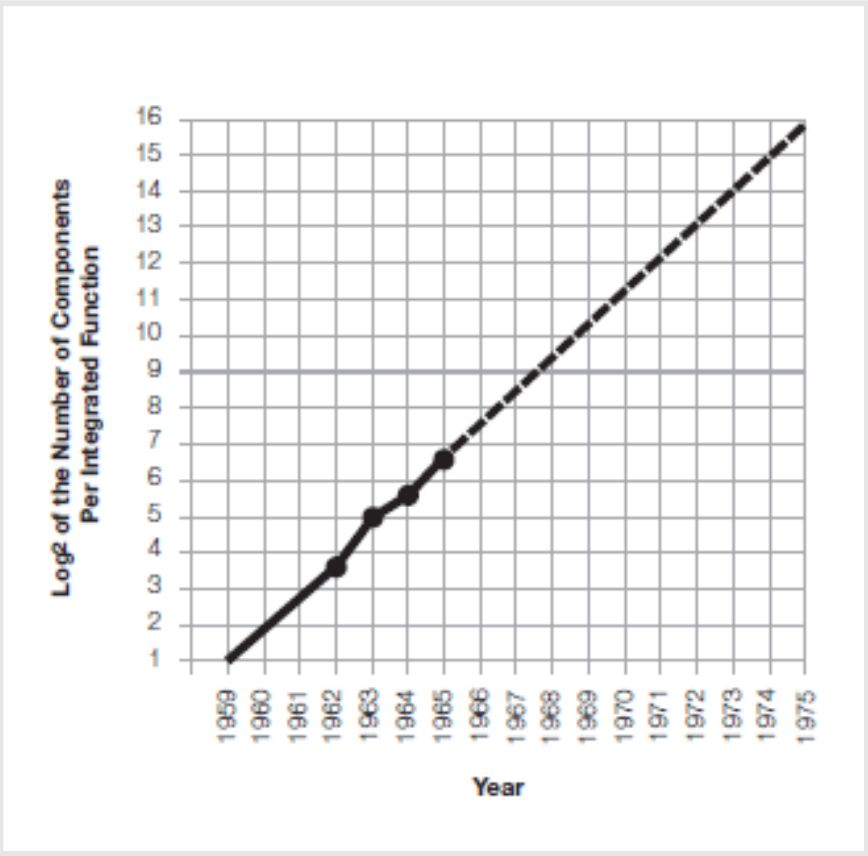
Source: Intel, VLSI Research

A Very Visual Example of Scaling



Source: Intel

Moore's Law – It's All About Economics



"**<u>Reduced cost</u>** is one of the big attractions of integrated electronics, and the cost advantage continues to increase as the technology evolves toward the production of larger and larger circuit functions on a single semiconductor substrate."

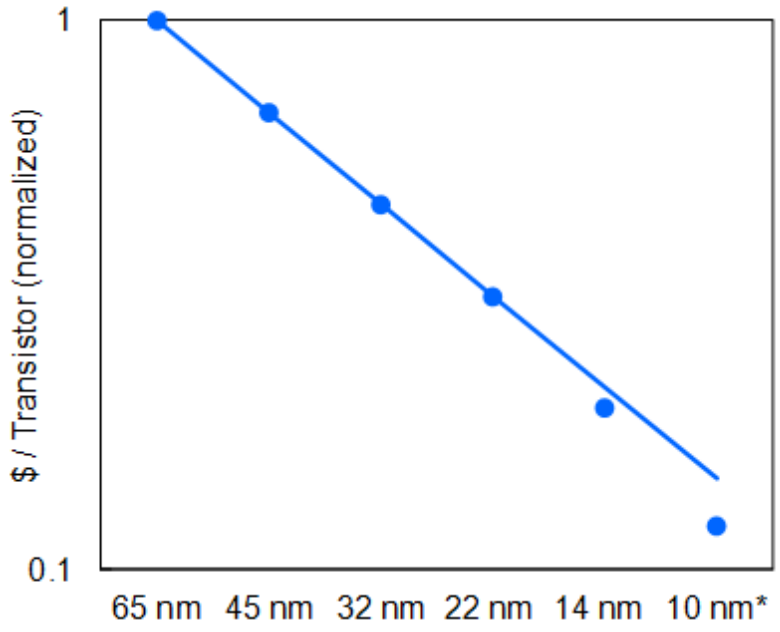
"*Cramming more components onto integrated circuits*", Electronics, Volume 38, Number 8, April 19, 1965

Source: Intel

But It's Not Just Economics

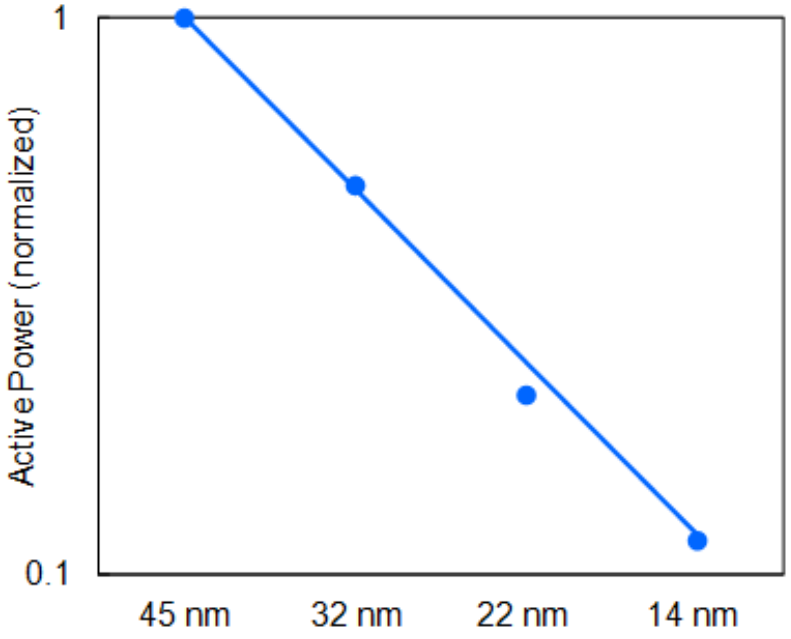
Cost and Power

Lower Cost per Transistor



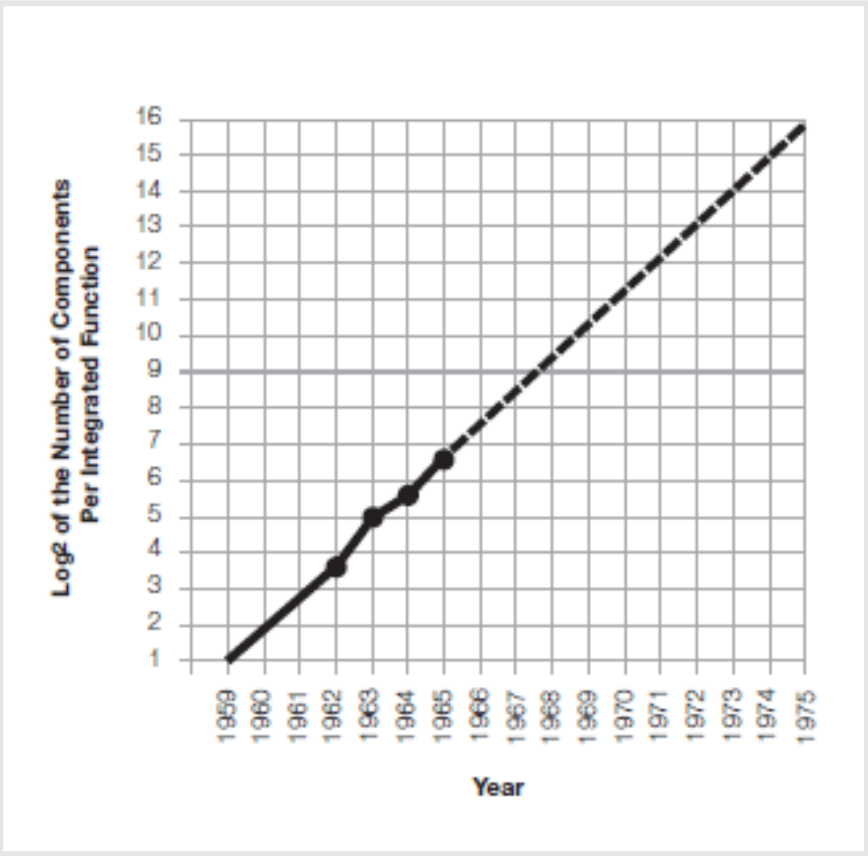
* Forecast

Lower Active Power



Source: Intel

Moore's Law – Economics AND Power



Heat problem

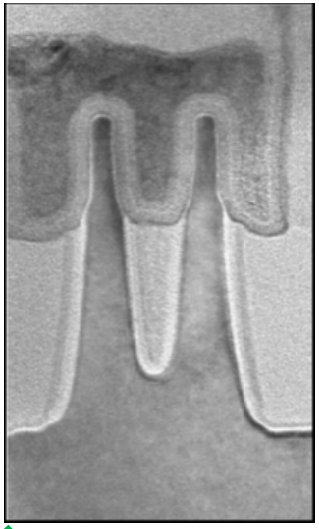
"Will it be possible to remove the heat generated by tens of thousands of components in a single silicon chip?"

"*Cramming more components onto integrated circuits*", Electronics, Volume 38, Number 8, April 19, 1965

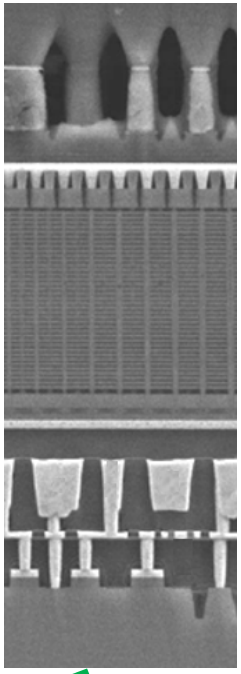
Source: Intel

What About 3D?

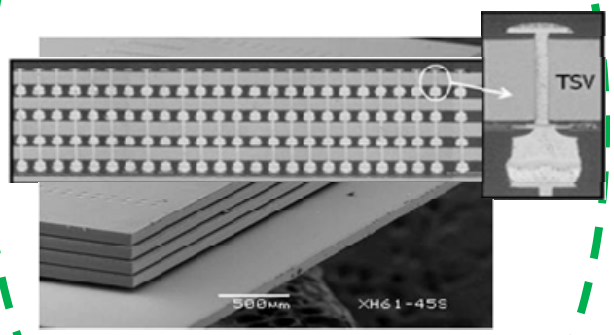
FinFETs



3D NAND



Die Stacking

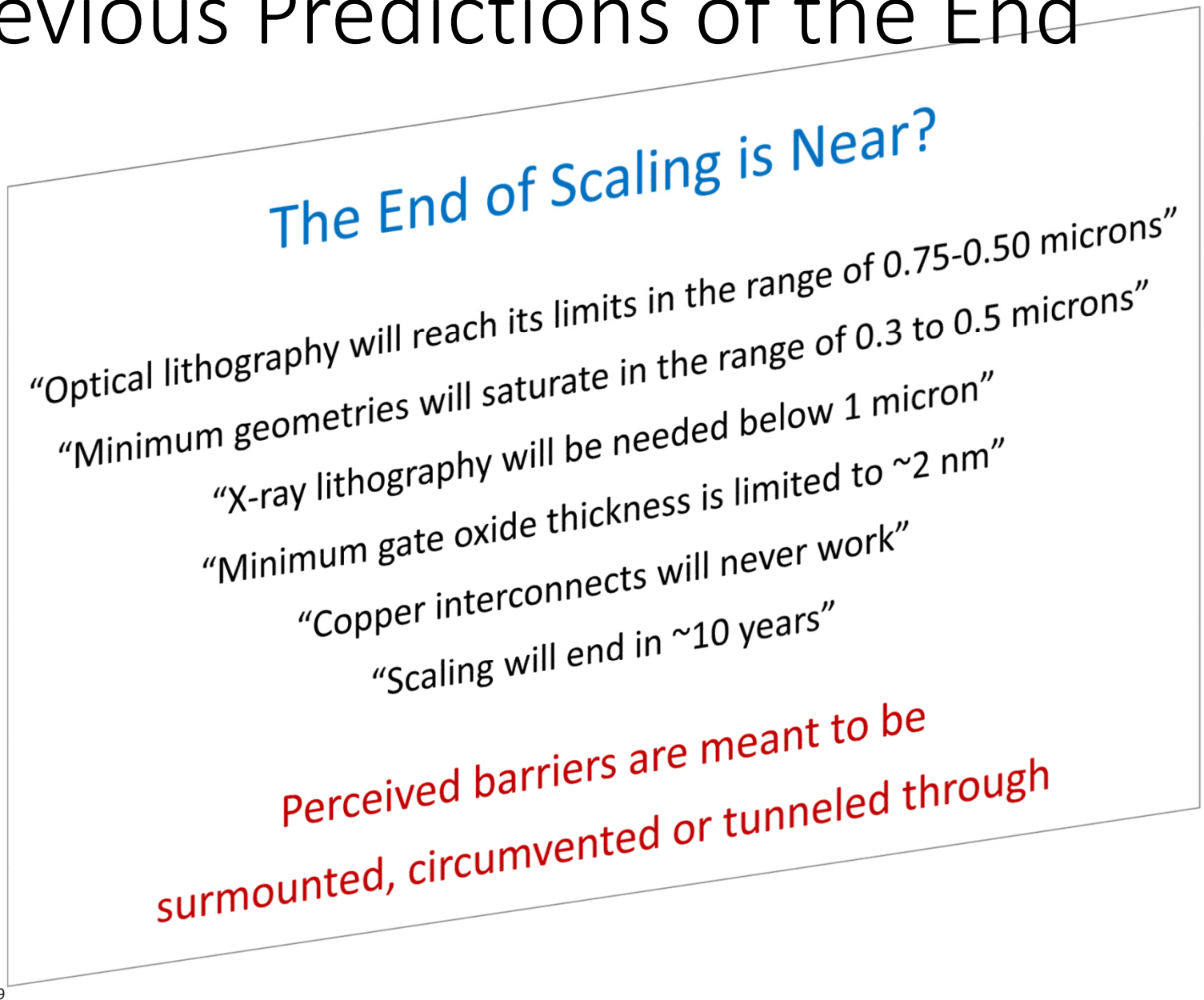


Enabling
Moore's Law

Enabling
Form and Function

Sources: Intel, K. Parat and C. Dennison, IEDM2015,
B. Sabi, SEMI Symposium Jan 2016

Previous Predictions of the End



Source: M. Bohr, ISSCC 2009

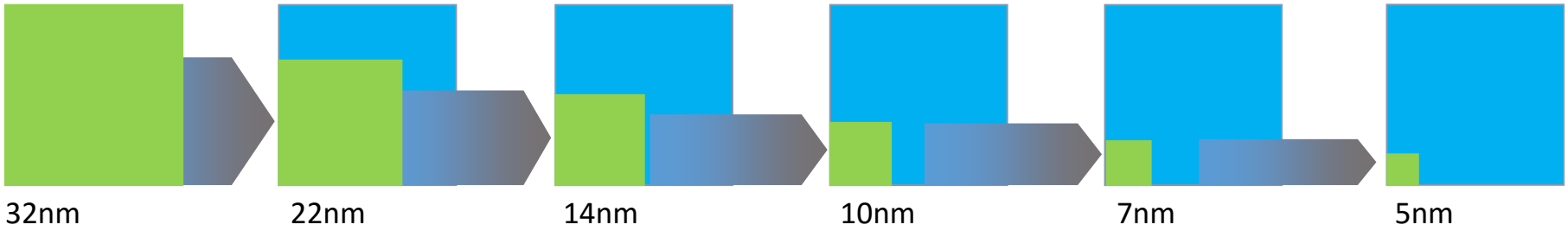
Recent Predictions are on AFFORDABILITY

"Signs are at last accumulating, however, which suggest the law is running out of steam. It is not so much that physical limits are getting in the way …
If **Moore's law has started to flag, it is mainly because of economics**."
The Economist explains The end of Moore's law, April 19th 2015

"**If lithography costs rise fast, Moore's Law as we know it will come to a quick halt**. And there are signs that the end could come quite soon."
C. Mack, *The Multiple Lives of Moore's Law*, IEEE Spectrum, March 30, 2015

"… some companies for the first time are **unable to reduce the cost** of each tiny transistor."
D. Clark, Moore's Law Shows Its Age, Wall Street Journal, April 17, 2015

Economics of Moore's Law



Same circuitry
~ half the space
(cost reduction)

OR

Twice the
circuitry in the
~ same space
(architectural
innovation)

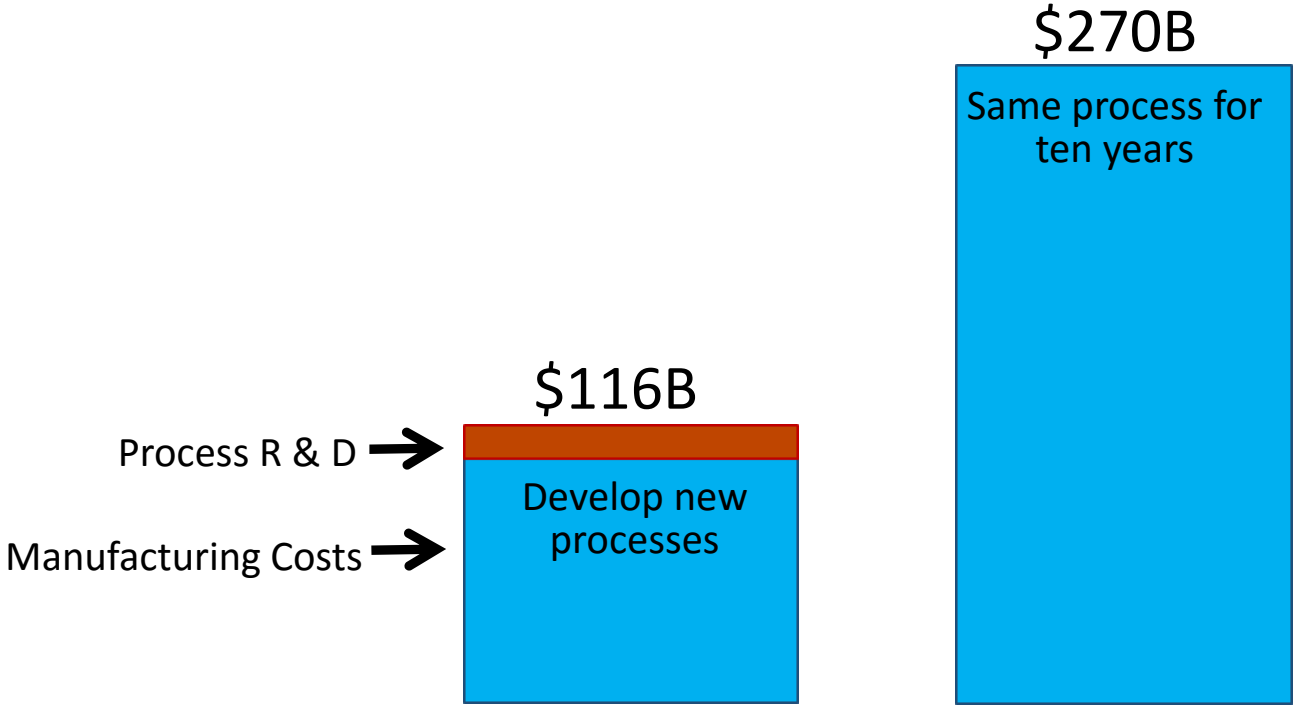
=

Optimized by design
for best
performance/cost

Moore's Law Enables Innovation and Cost Reductions

Source: Intel

Ten Year Model of Manufacturing and Process R & D



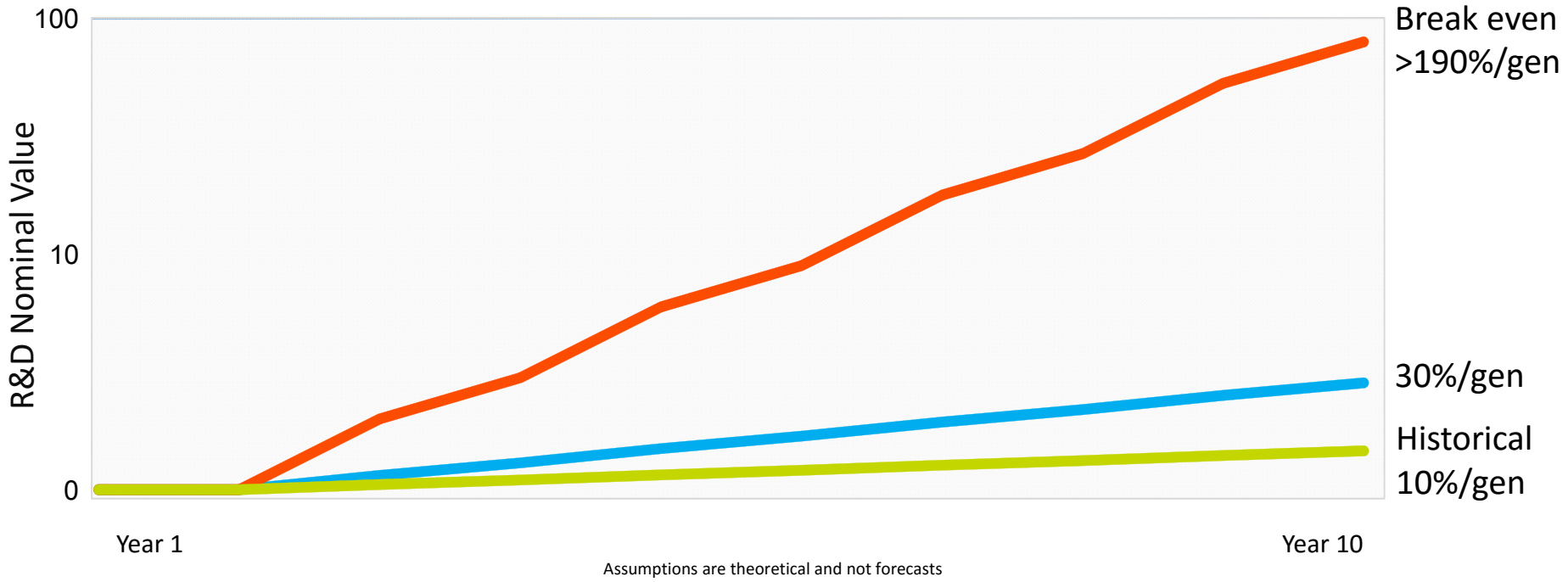
Assumptions are theoretical and not forecasts.

Advancing Process Technology Lowers Costs

Source: Intel

The Role of R&D costs

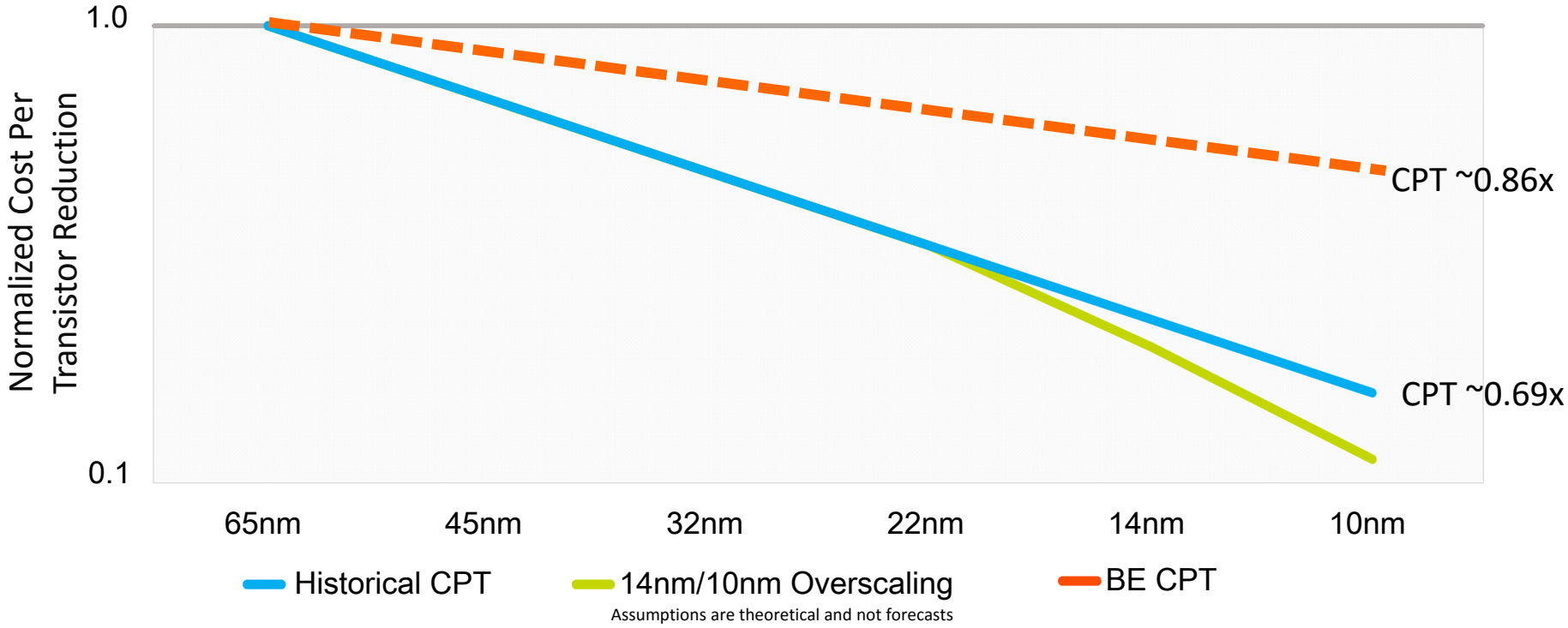
By Year 10, R&D Would Be > $80B/ Year



Higher R&D investment growth will NOT limit Moore's Law

Source: Intel

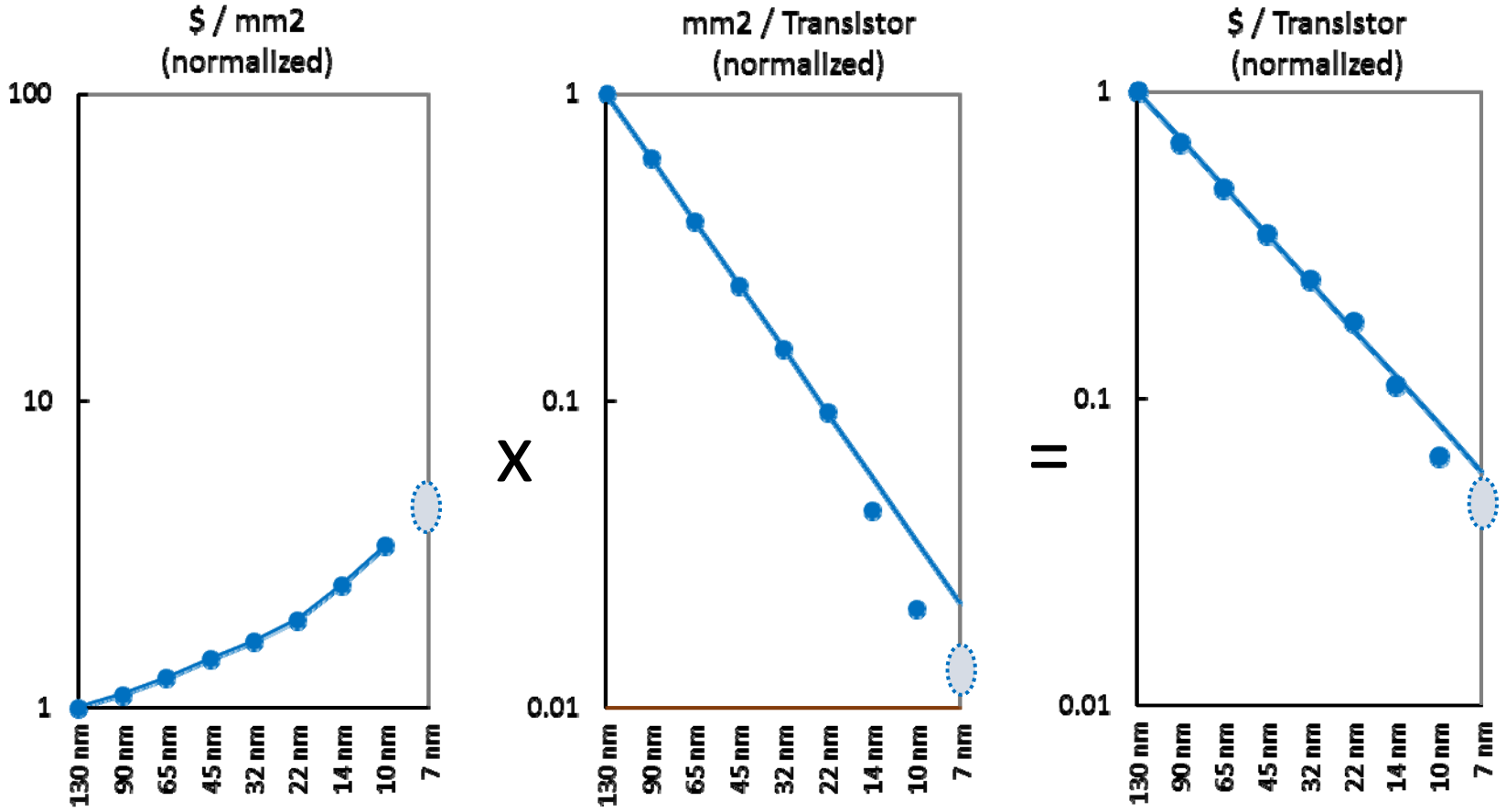
Importance of Cost Per Transistor



Poorer CPT scaling could challenge economic benefits

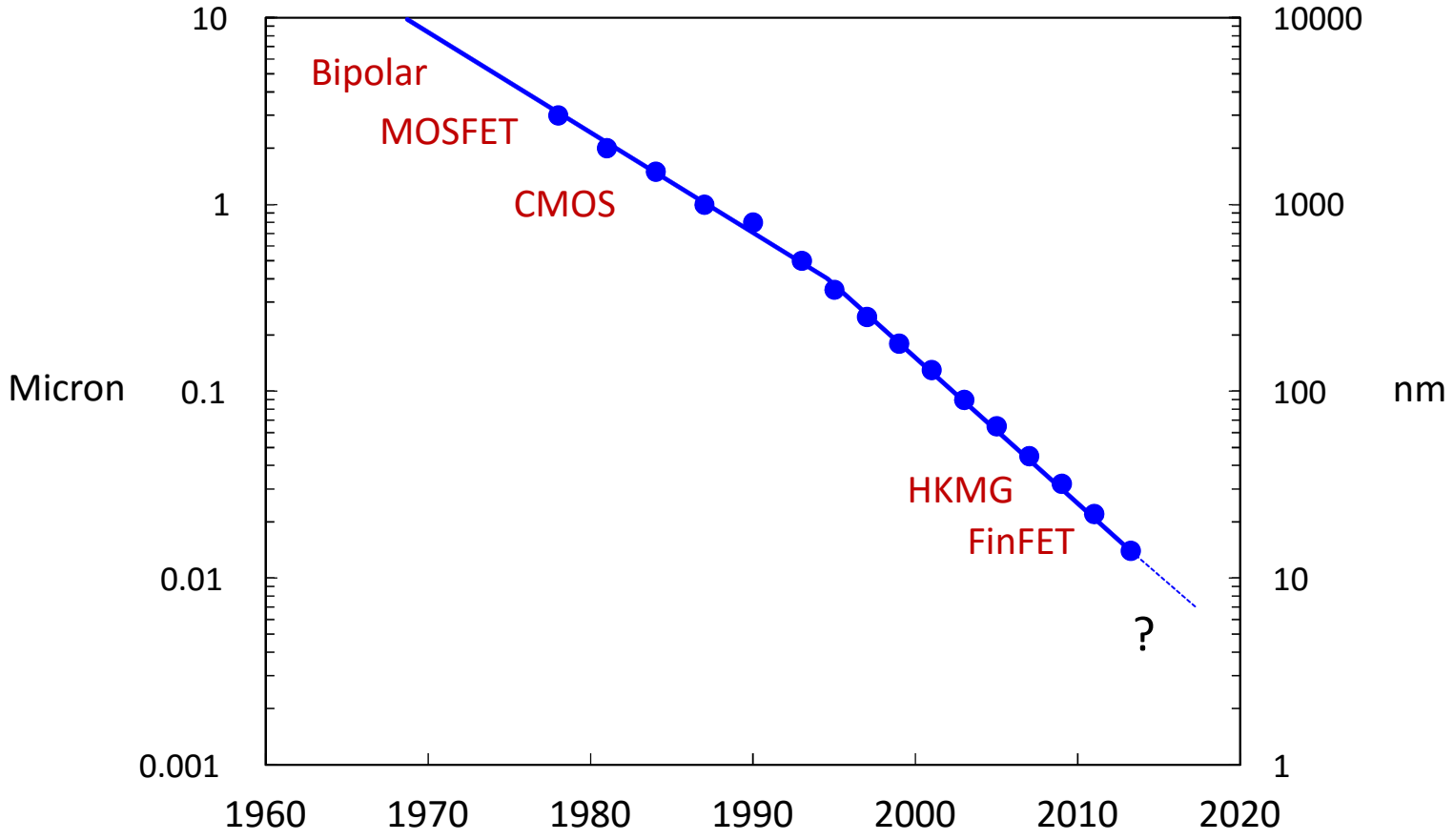
Source: Intel

Offsetting Wafer Cost with Density



Source: Intel

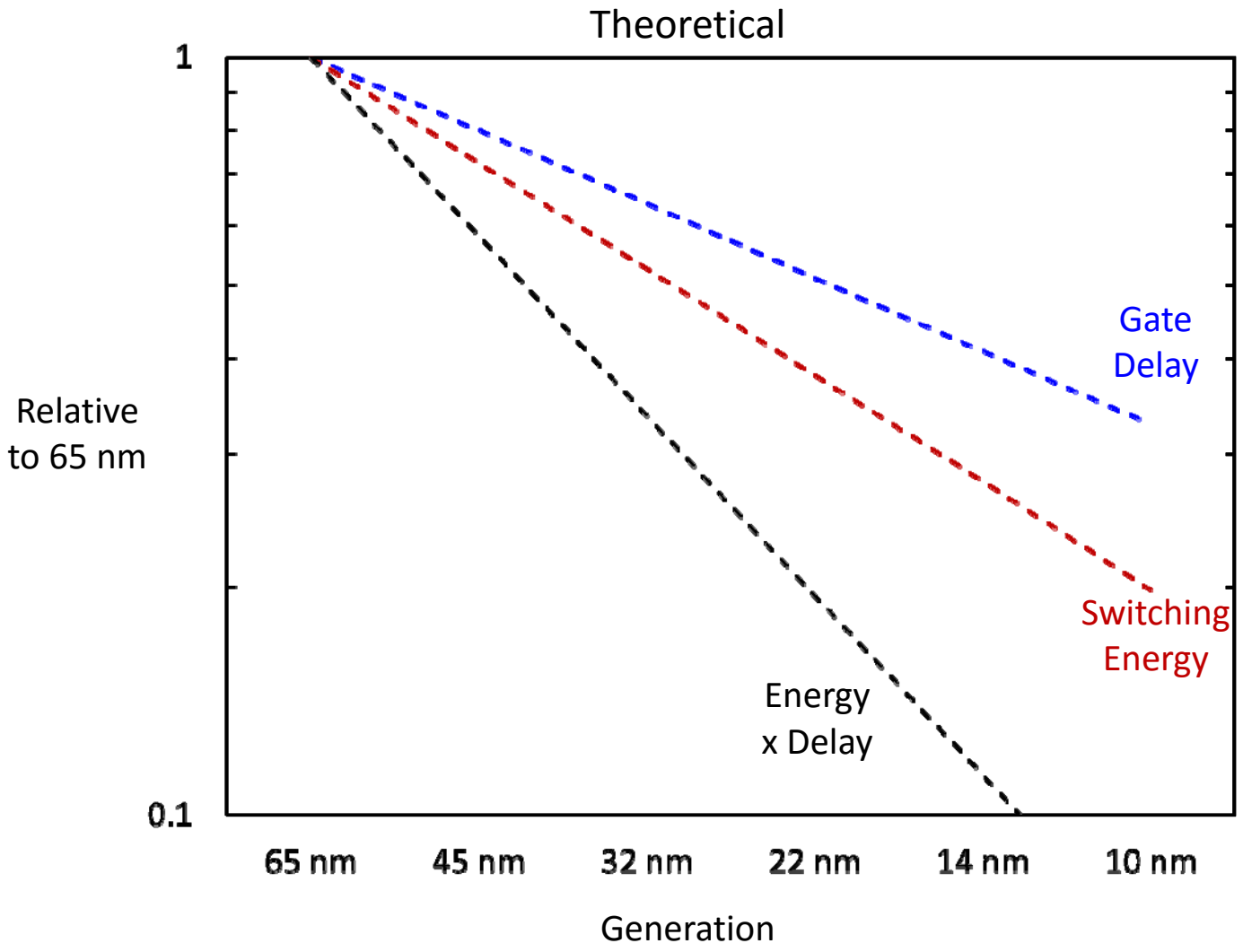
Technology Transitions Driven by Power



Process and device innovation has always been an indispensable part of continuing Moore's Law

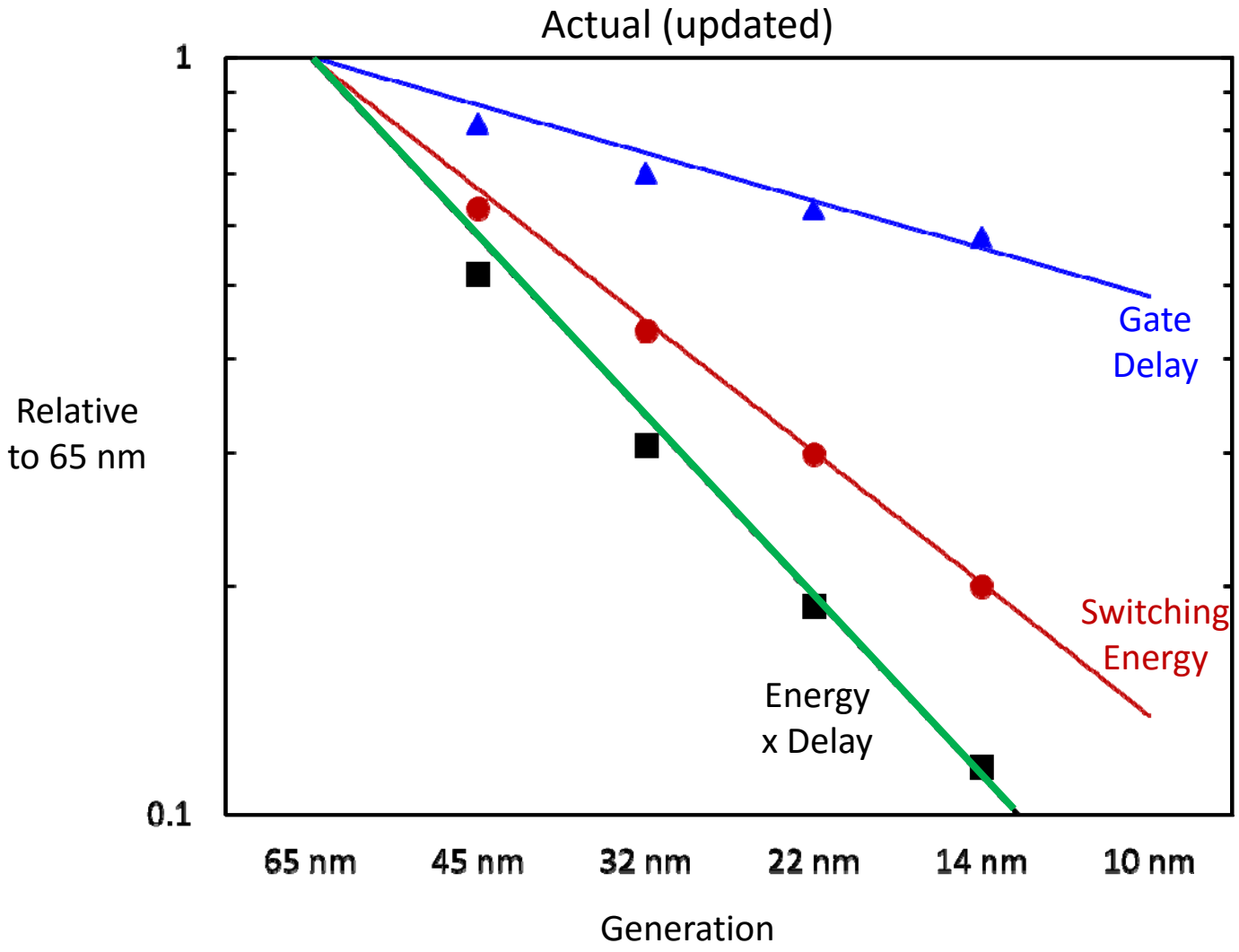
Source: Intel

Power Efficiency Supplants Delay



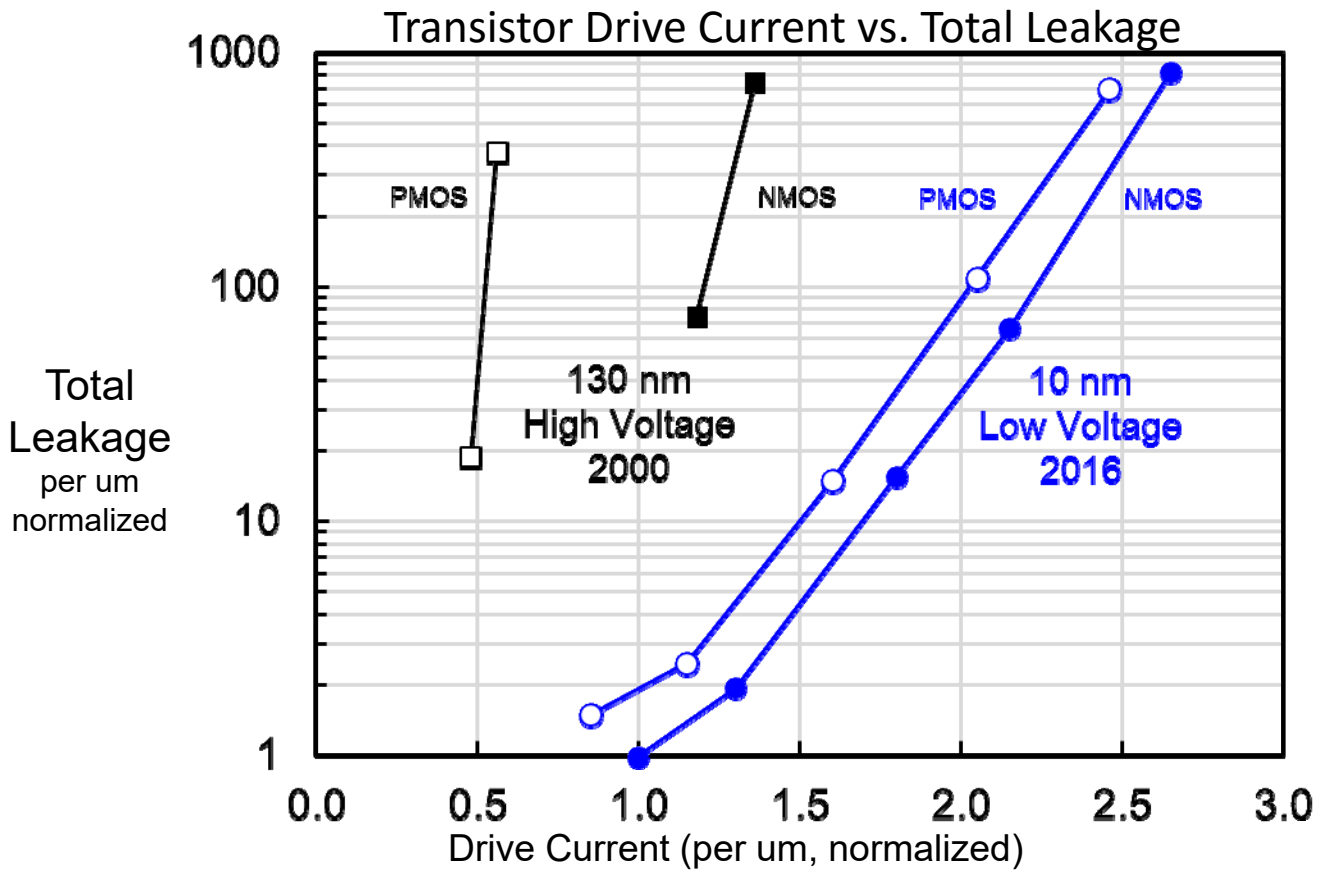
Source: Intel

Power Efficiency Supplants Delay



Source: Intel

Enhanced Capability Comes with Increased Complexity



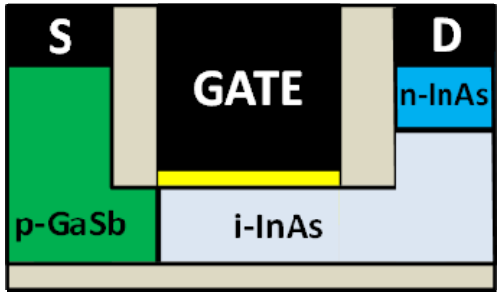
Logic technologies in 2000 provided just 2 Vts

Intel's 10 nm logic technology provides 5 Vts spanning ~700x in total leakage and ~2.7x in performance

Source: Intel

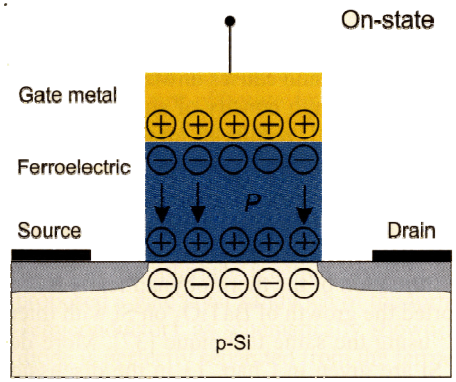
Options for Beyond CMOS

Electronic



Tunneling FET

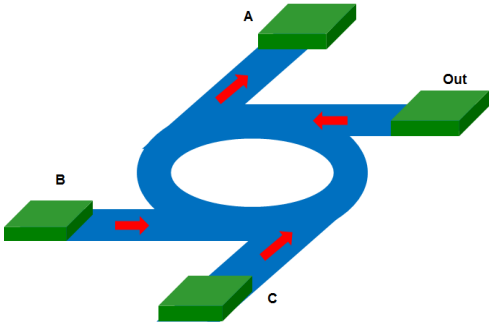
Ferroelectric



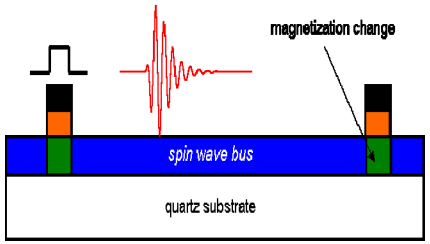
FEFET

Source: Intel

Spintronic

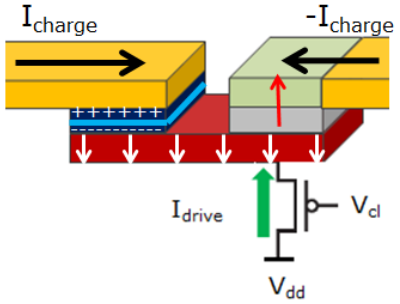


Spin Majority Gate (SMG)



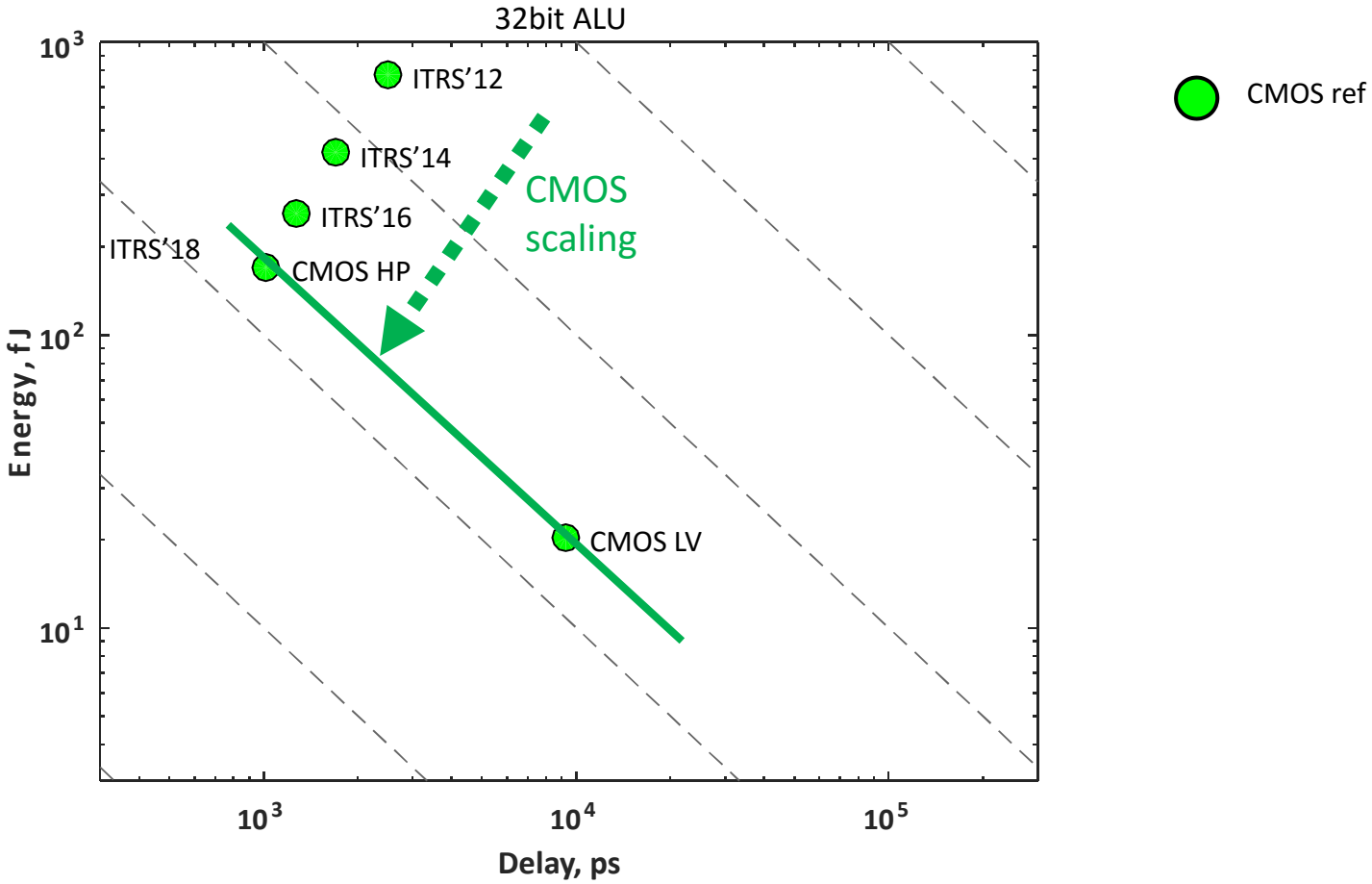
Spin Wave Device (SWD)

Magneto-Electric Spin-Orbital (MESO)



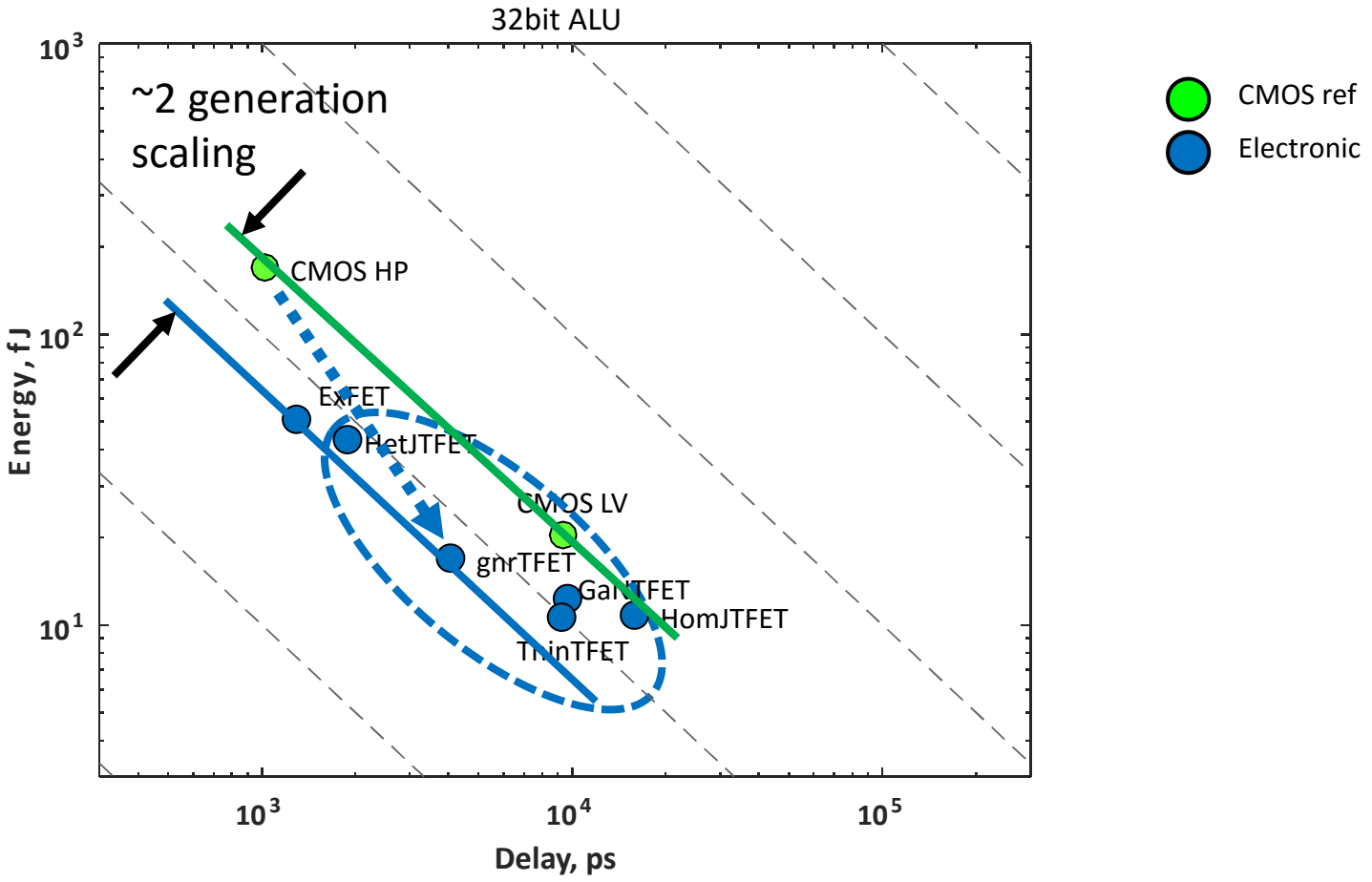
Device	Physics
MOSFET	Conduction over gate controlled barrier
Tunneling FET	Quantum tunneling band to band conduction through a gate controlled barrier
MESO	Magneto-electric effect Spin Orbit Torque effect

The Changing Measure of Improvement



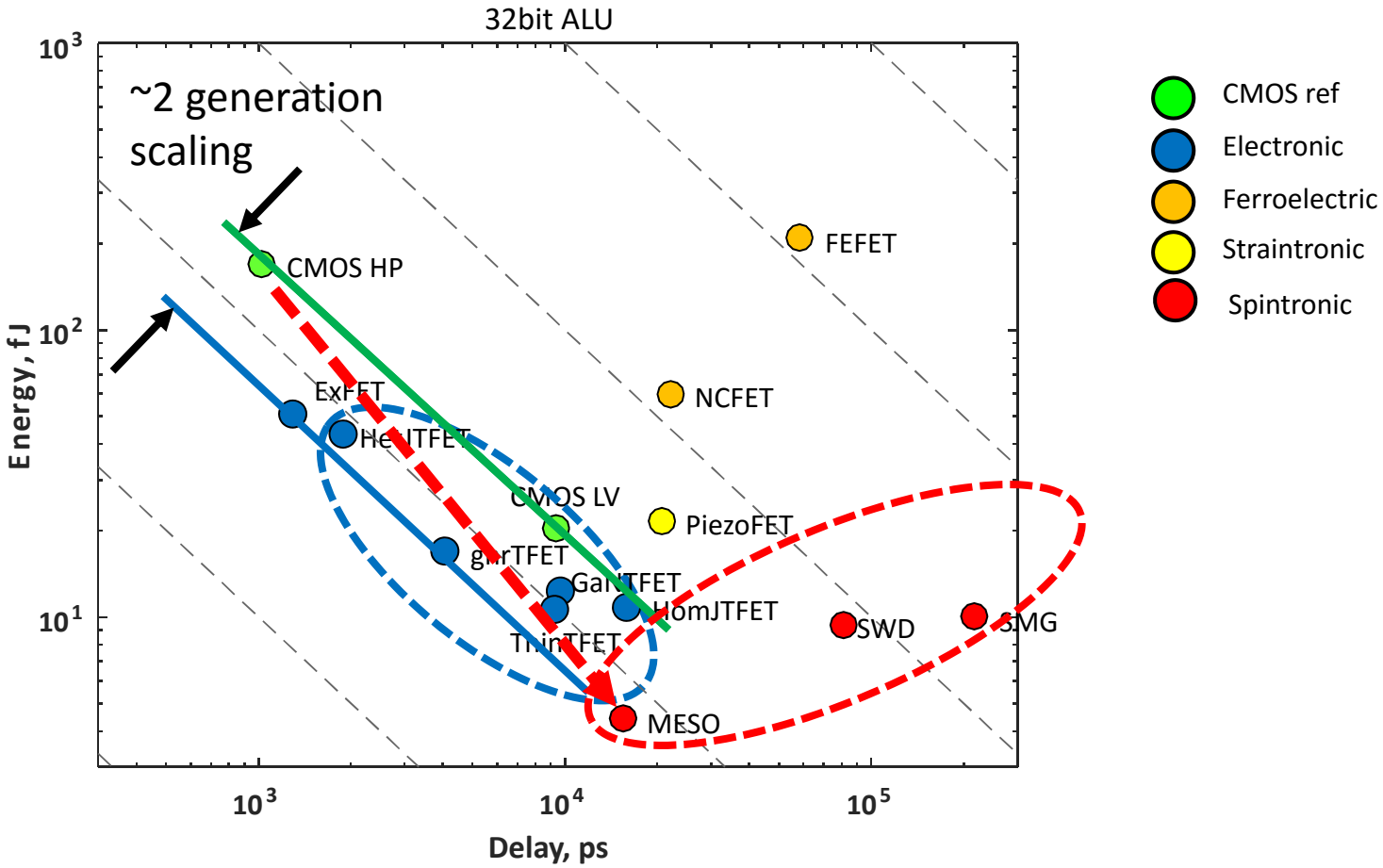
Source: ITRS 2011

The Changing Measure of Improvement



Sources: ITRS 2011, Nikonov and Young, IEEE JxCDC, 1, 3-11 (2015);
Manipatruni, Nikonov and Young, Arxiv cond-mat 1512.05428 (2015)

The Changing Measure of Improvement



Sources: ITRS 2011, Nikonov and Young, IEEE JxCDC, 1, 3-11 (2015);
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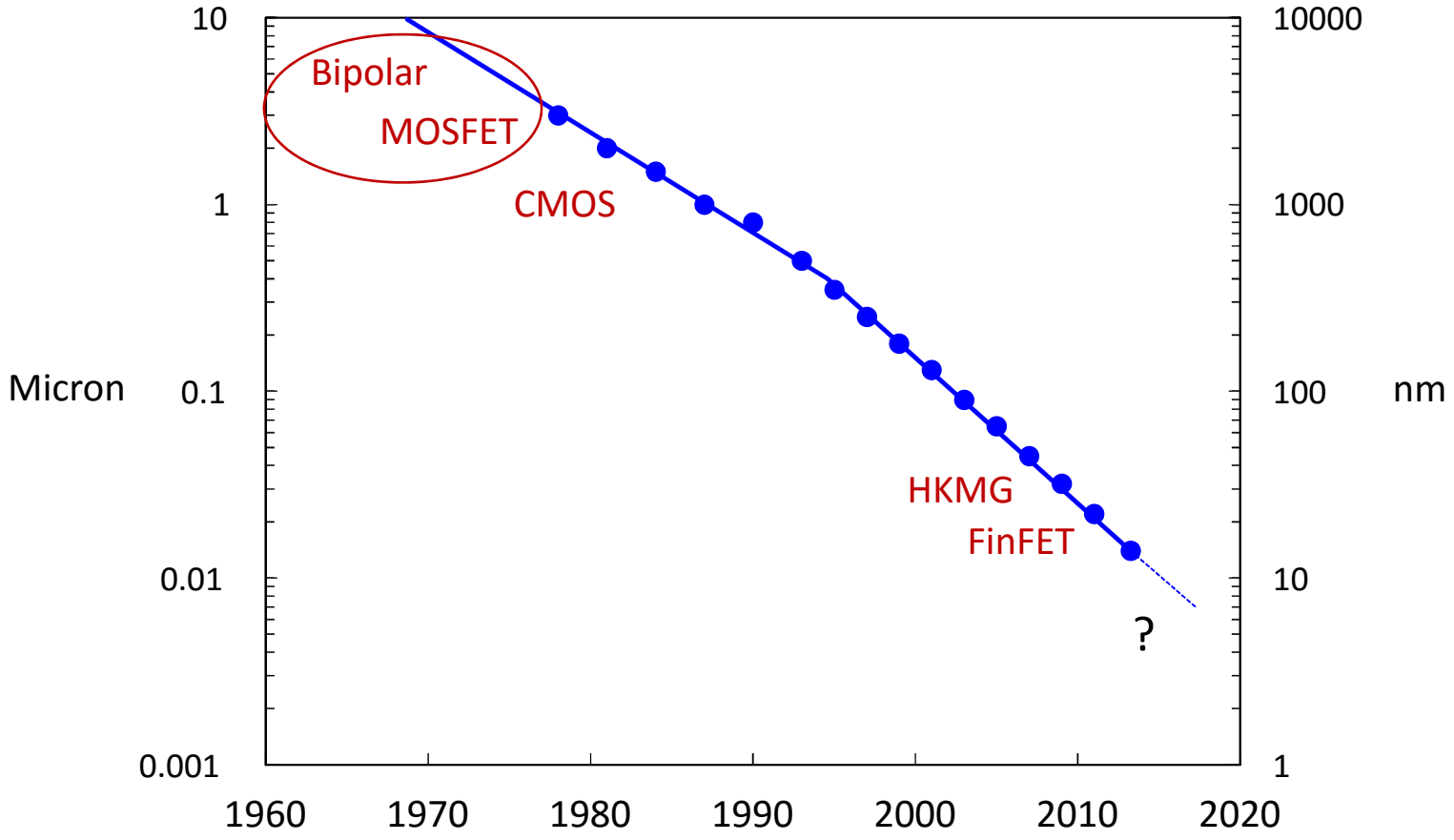
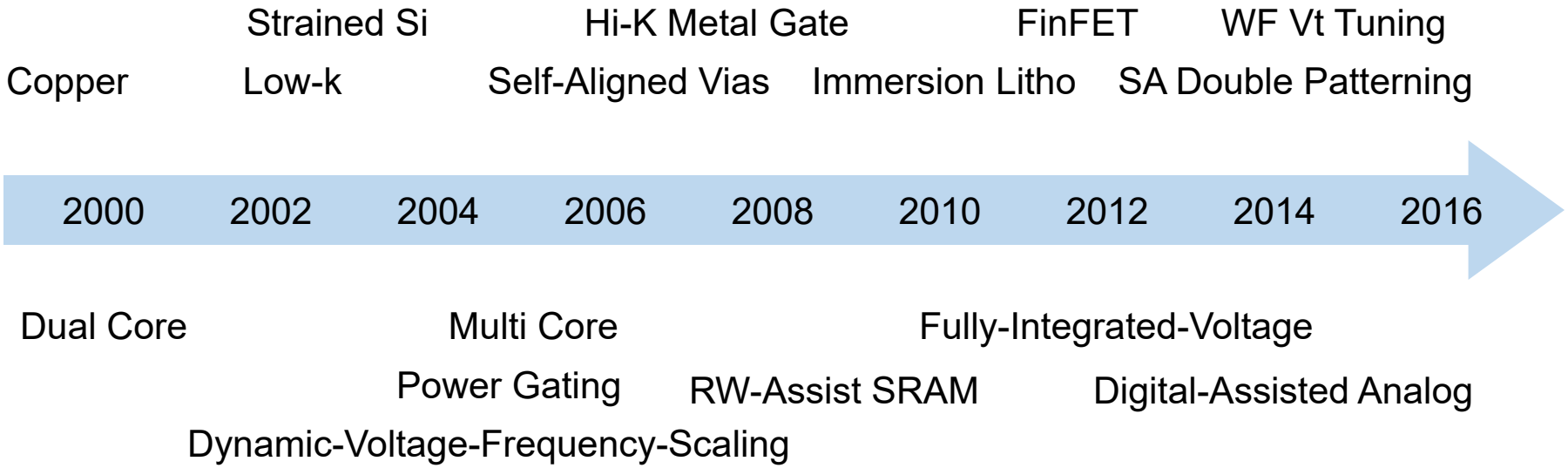
Technology Transitions Driven by Power



Source: Intel

Improvement Requires Innovations

Process Technology Innovations

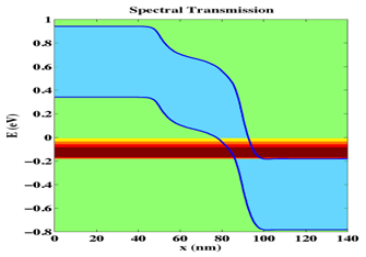


Design and Architecture Innovations

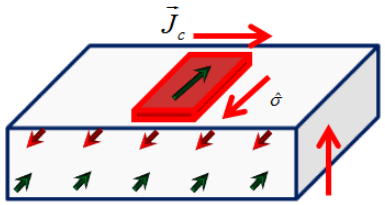
Source: Intel

Some Implications of "Beyond CMOS" Computing

Hierarchical Level	CMOS	Beyond CMOS
Materials	Silicon	III-V , Correlated oxides, High-Z metals
Device	MOSFET	Tunneling-FET MESO (Magneto-Electric / Spin Orbit Torque)
Interconnect	Electronic	Electronic
Circuits	CMOS	Electronic, Spintronic
Architecture	von Neumann	von Neumann, Non- von Neumann
Memory	SRAM/DRAM	Electronic, Spintronic

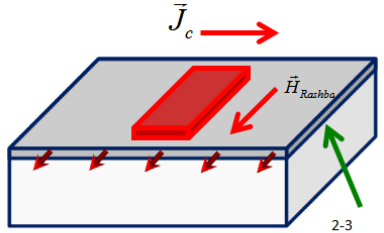


Bulk Spin Hall Effect



$$\vec{J}_s = \theta_{SHE}(\hat{\sigma} \times \vec{J}_c)$$

Interface Rashba Effect



$$\vec{H}_{Rashba} \alpha (\hat{z} \times \vec{J}_c)$$

- Beyond CMOS devices are <u>different</u>
- Beyond CMOS provides opportunities for active <u>research</u>
- Beyond CMOS will not replace CMOS, it will <u>augment</u> CMOS

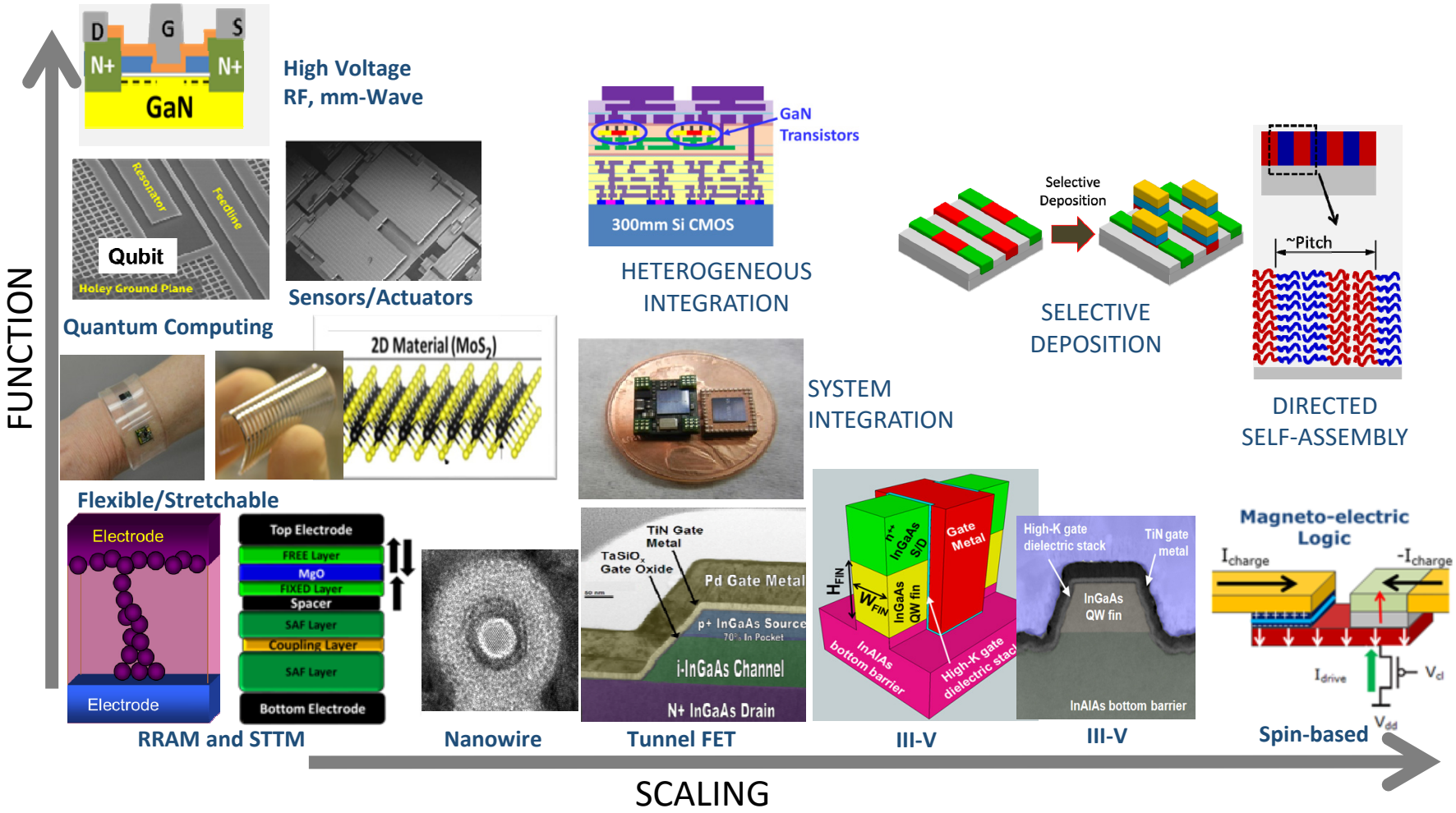
Sources: Intel, M. Luisier ETH Zurich

Summary

- Moore's Law is fundamentally about cost/function
  - However to enable more functions, power reduction is critical
- The economics of Moore's Law remain sound
  - However increased complexity must be offset by improved density
- The future of technology will be one of major transitions
  - Focus (speed to power)
  - Form (CMOS to ?)

Technology transitions will demand significant innovations in both architecture and design to harvest the benefits

The Future is Full of Opportunity



Source: Intel

Three Pillars Enabling the Internet of Everything (IoE)

Smart Everyday Objects, Information-Centric Networks and *Automated Real-Time Insights*

Sophie V. Vandebroek
Chief Technology Officer
Xerox

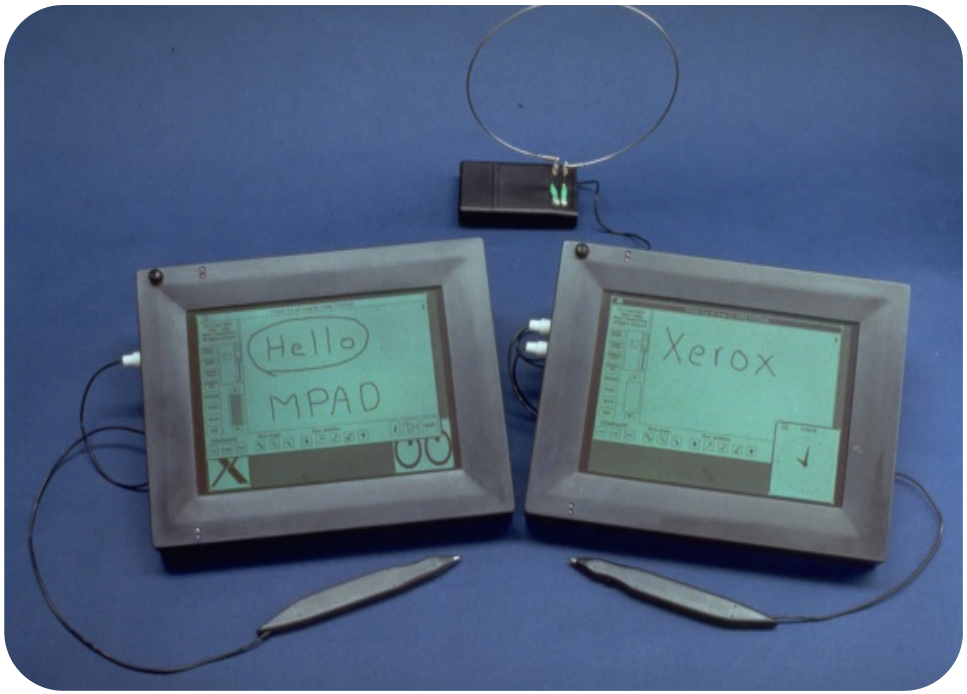
www.xerox.com/innovation

xerox

Early Internet of Everything vision

*"The most profound technologies are those that **disappear.***

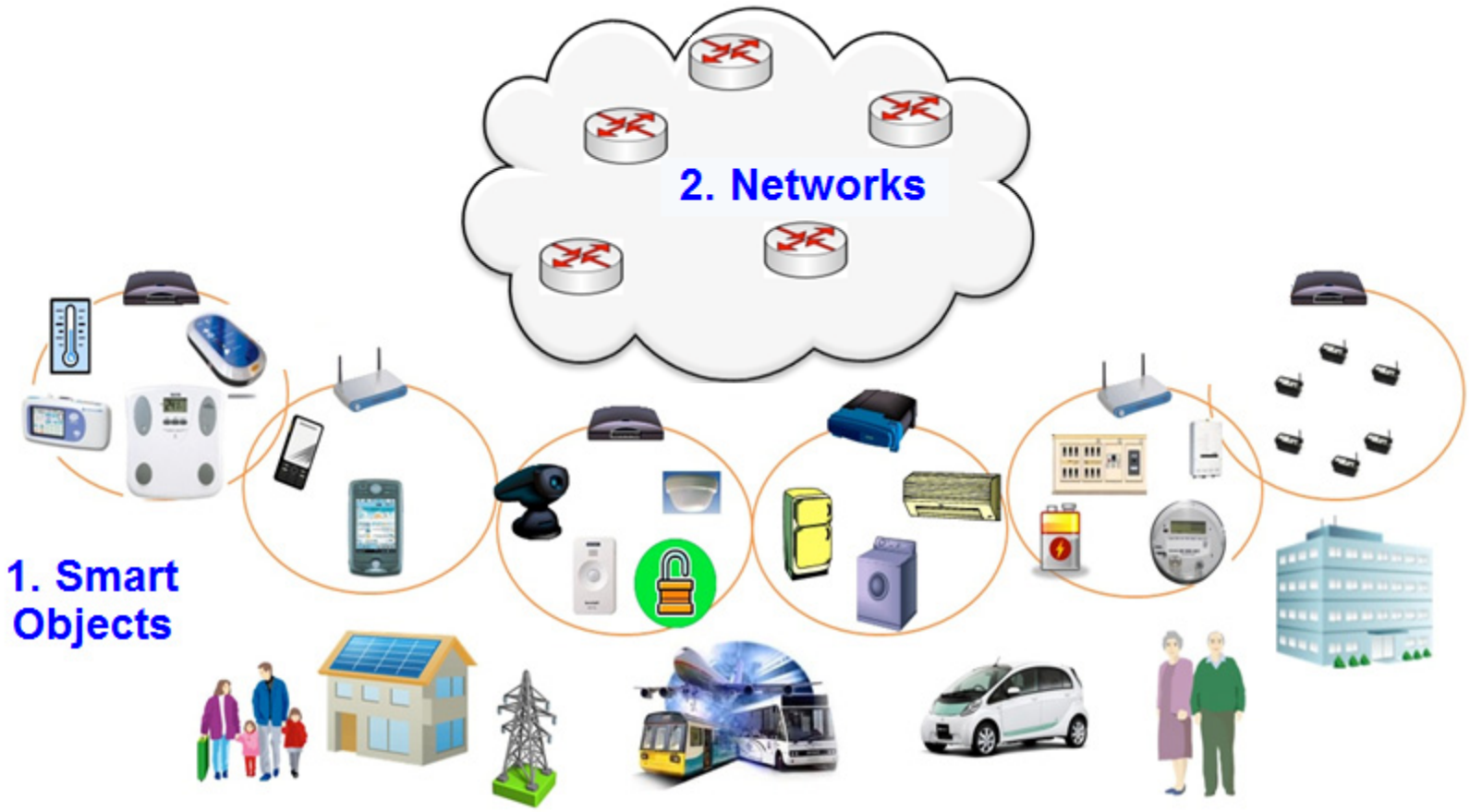
*They weave themselves into the **fabric of everyday life** until they are **indistinguishable** from it"*



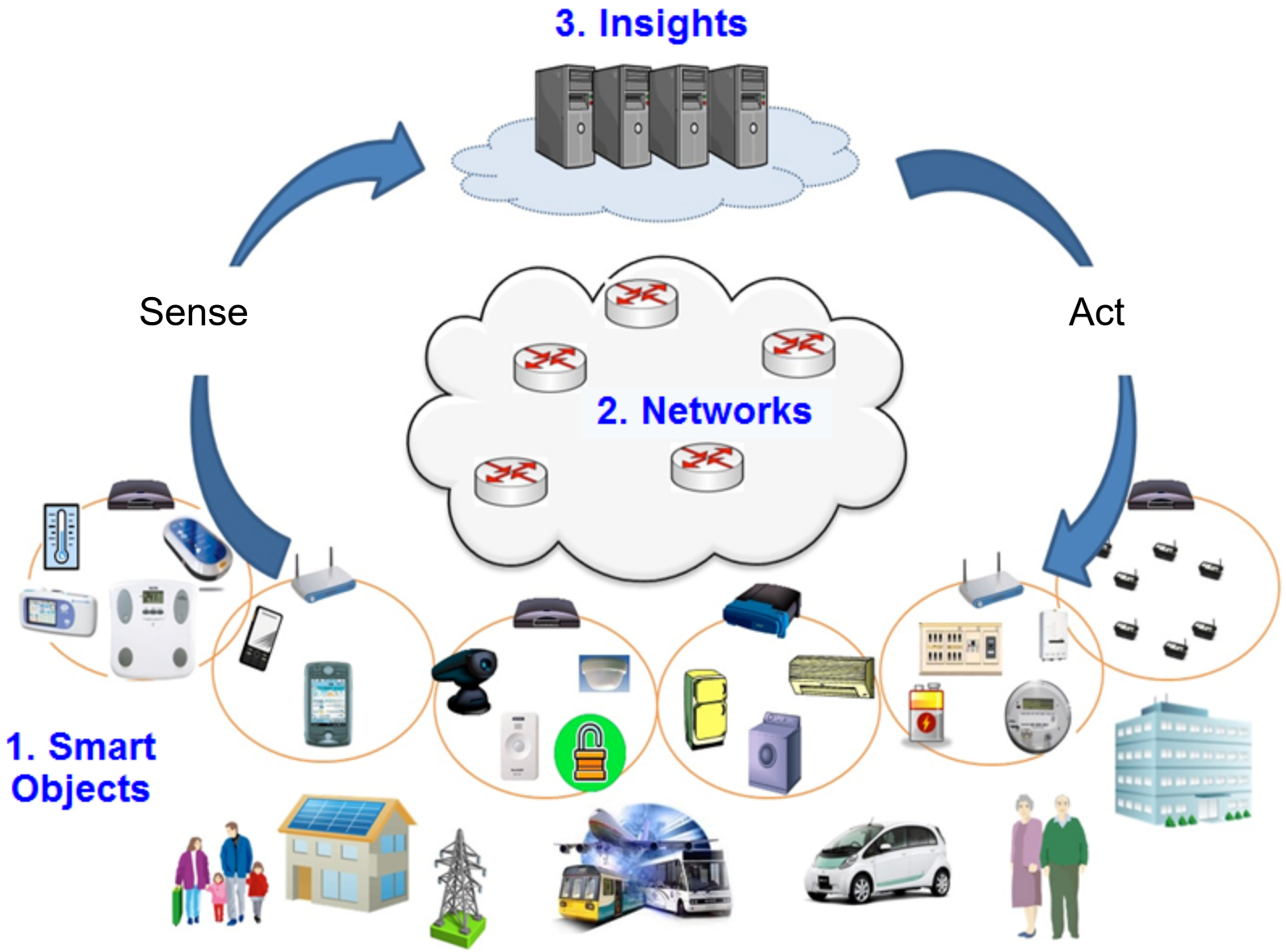
Mark Weiser, late '80s

PARC researcher and father of "ubiquitous computing"

Three pillars enabling the Internet of Everything



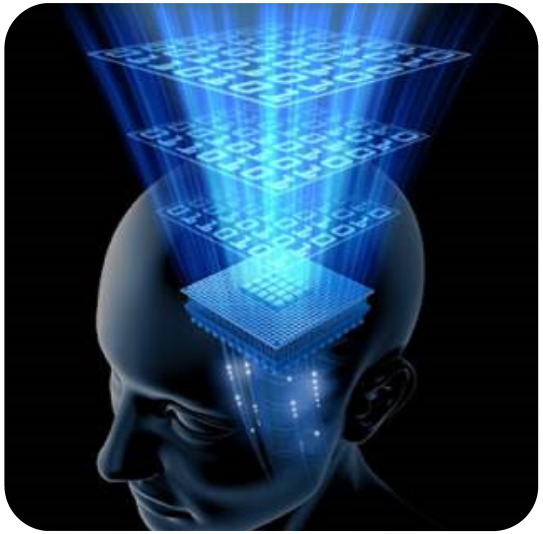
Three pillars enabling the Internet of Everything



Outline

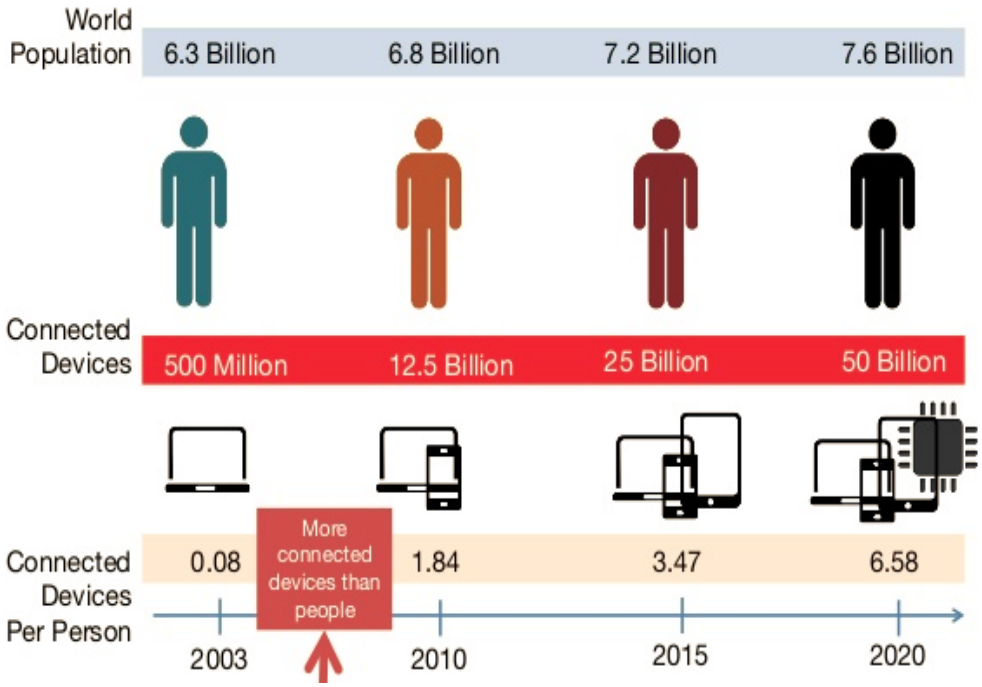
1. Smart Everyday Objects

2. Information-Centric Networks



3. Automated Real-Time Insights

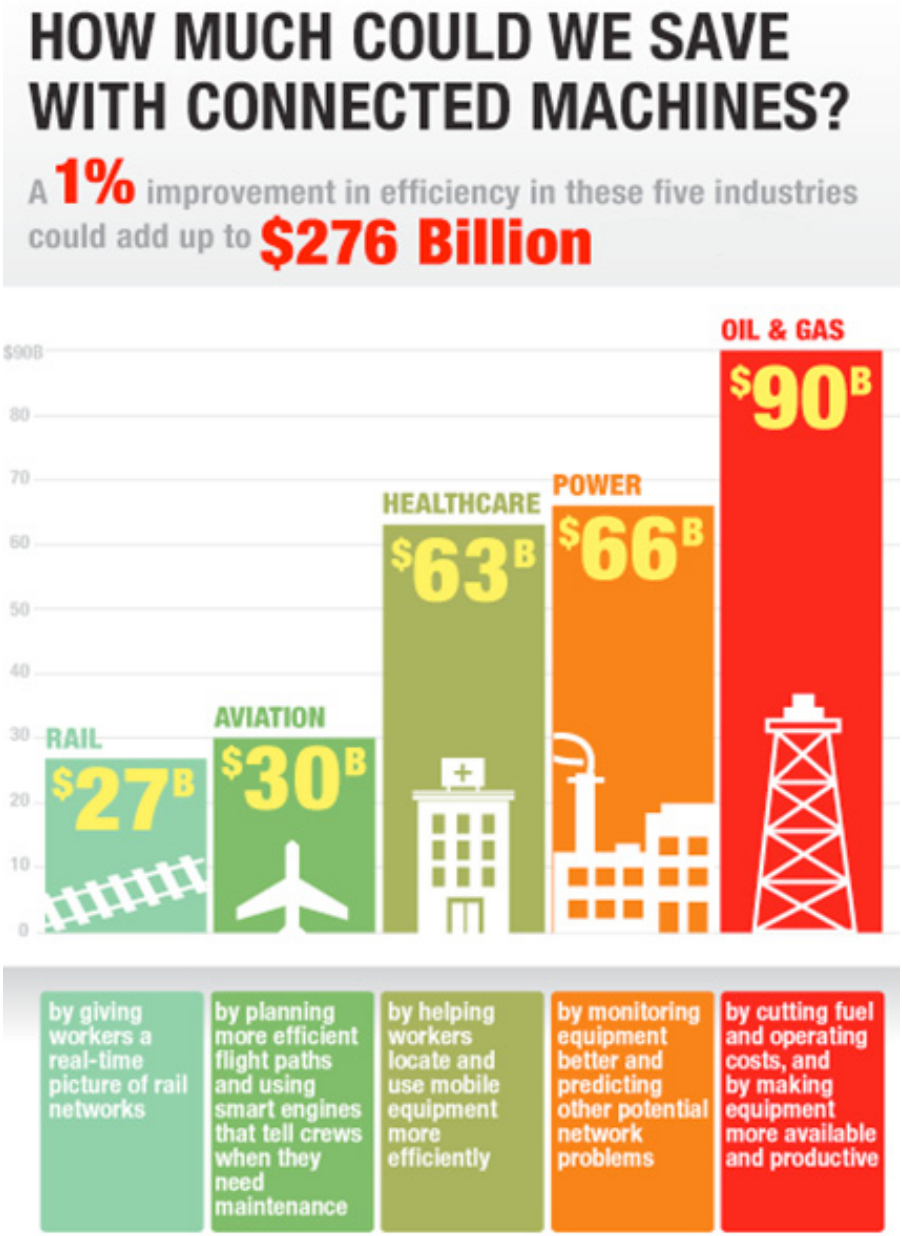
The Internet of Everything (IoE) is growing fast



Cisco

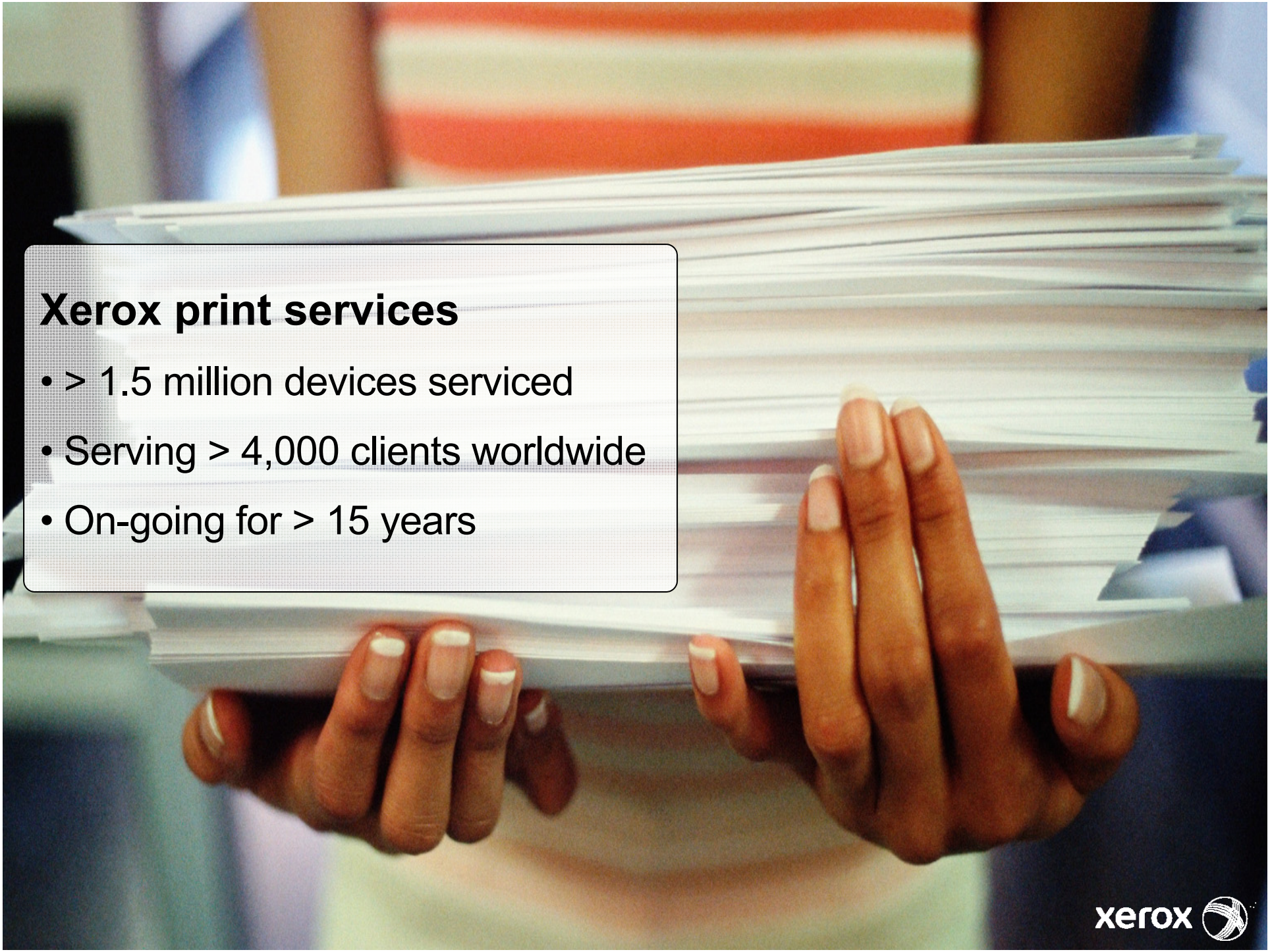
50 Billion connected objects by 2020

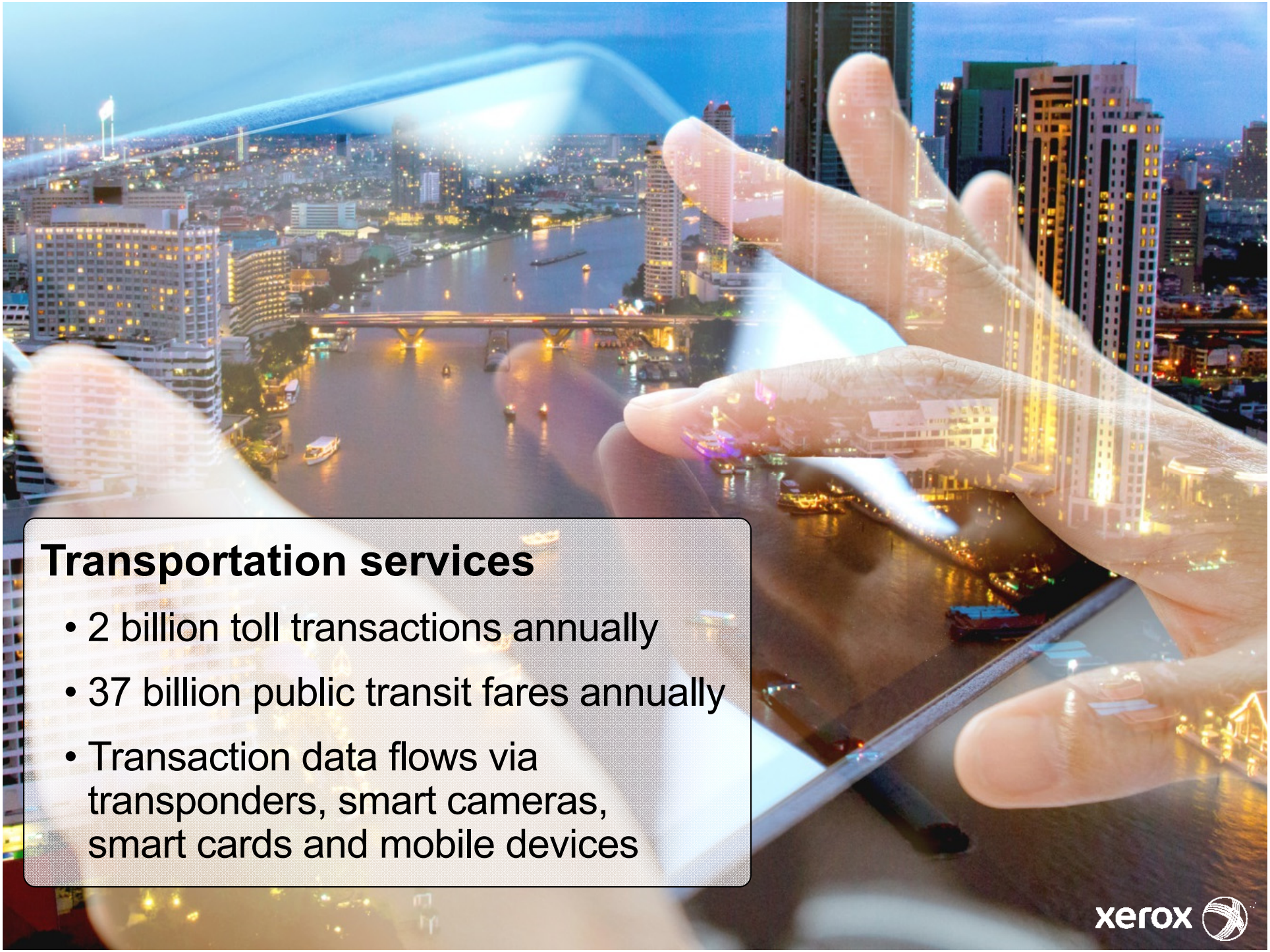
Creating tremendous **value** through greater **efficiency**



$1.7 Trillion by 2020

The Economist




Transportation services
• 2 billion toll transactions annually
• 37 billion public transit fares annually
• Transaction data flows via transponders, smart cameras, smart cards and mobile devices
xerox

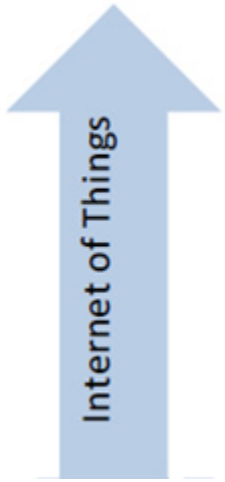
Outline

1. Smart Everyday Objects

2. Information-Centric Networks

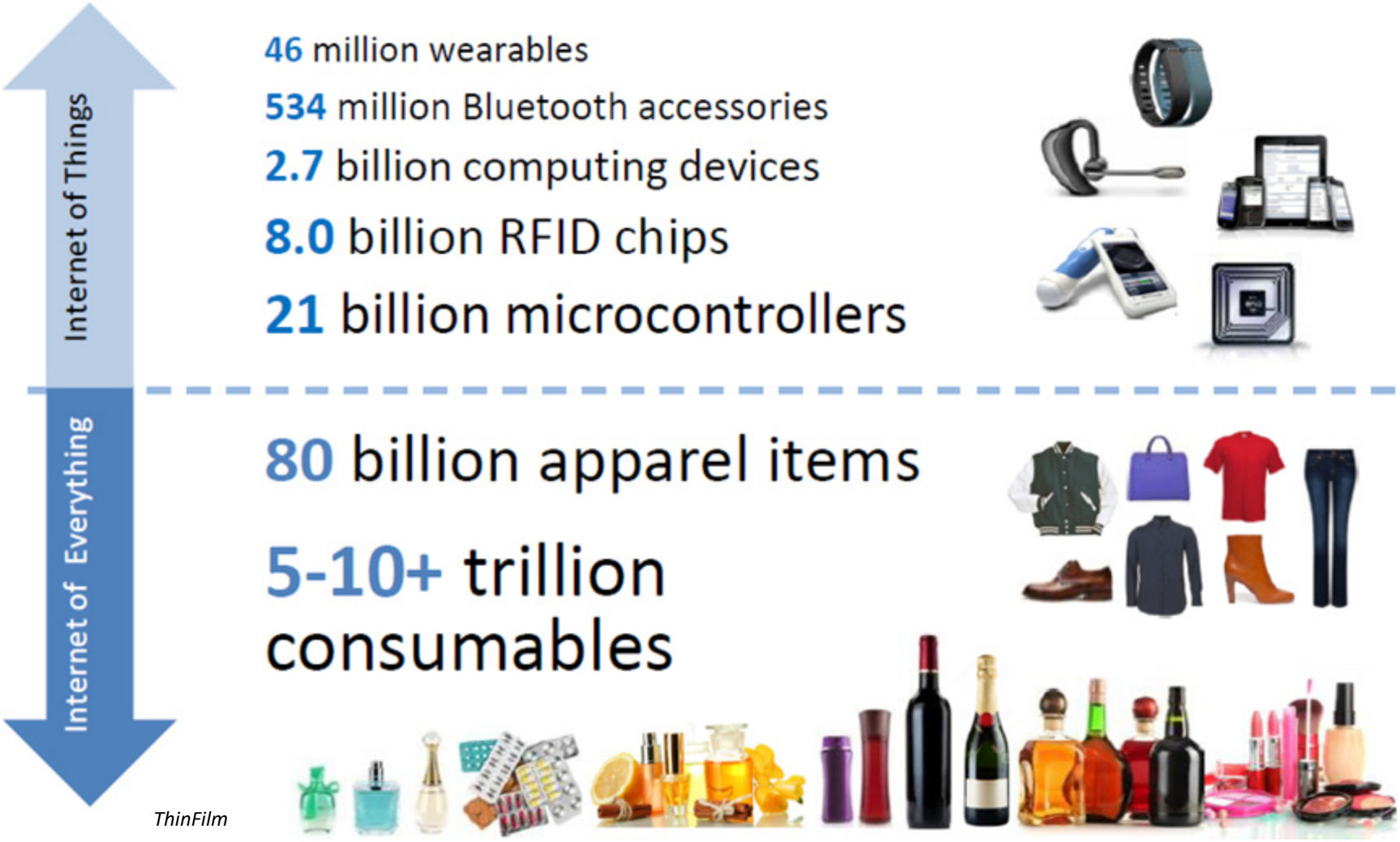
3. Automated Real-Time Insights

"The future is already here –
it's just not evenly distributed" William Gibson



46 million wearables
534 million Bluetooth accessories
2.7 billion computing devices
8.0 billion RFID chips
21 billion microcontrollers

"The future is already here –
it's just not evenly distributed" William Gibson



Creating **smart-enough** everyday objects

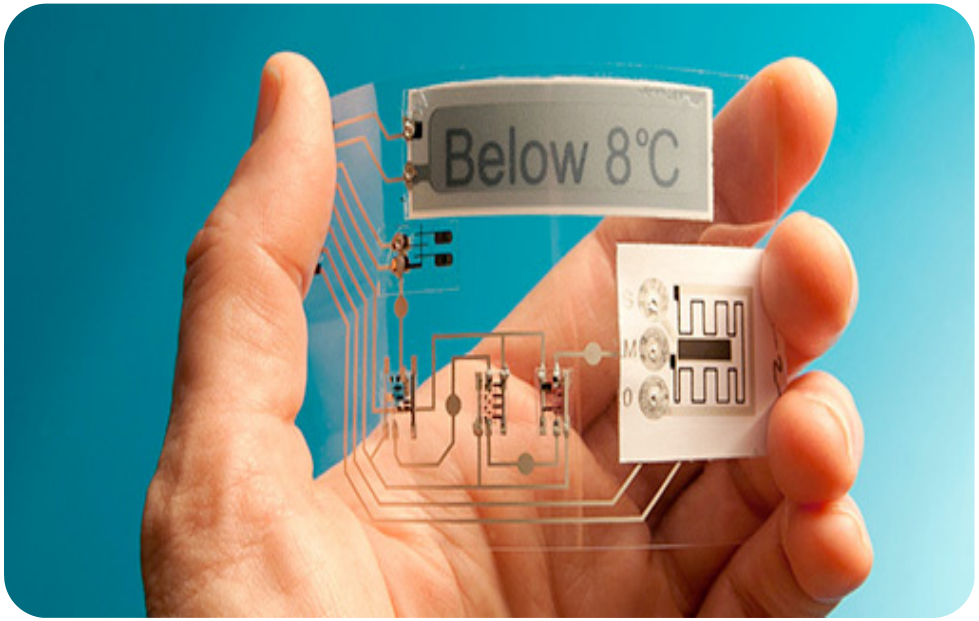
2016
Xerox printed memory for brand protection

Xerox in collaboration with ThinFilm

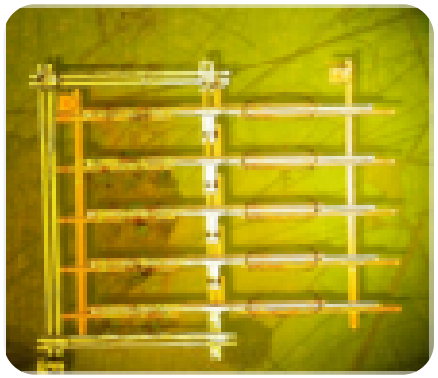
Smart-enough everyday objects **add functionality**

2016
Xerox printed memory for brand protection

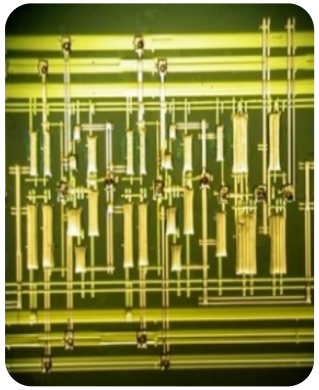
2017+
Smart printed labels for low-cost sensing



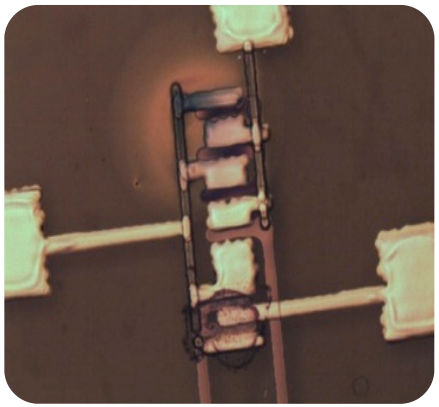
Printed electronic circuits building blocks



Oscillator

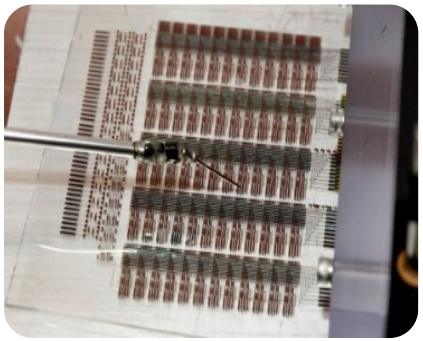


Shift register

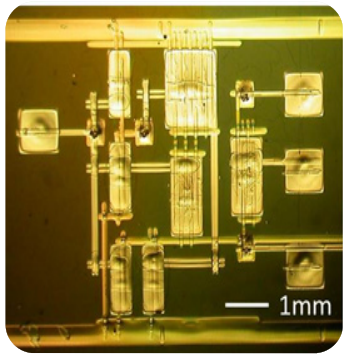


Amplifier

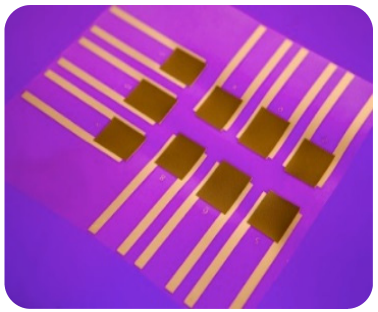
Active matrix
Thin Film Transistor



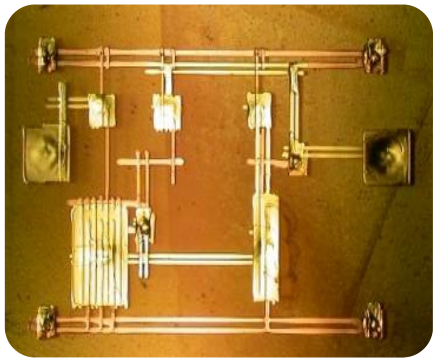
Decoder



Pulse generator

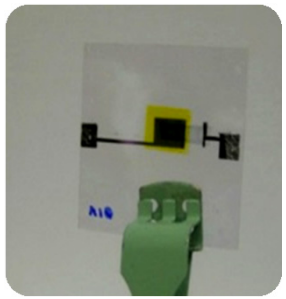


Temperature sensor

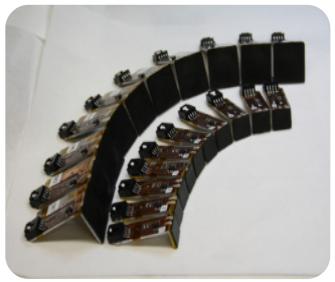


Trigger

Image sensor

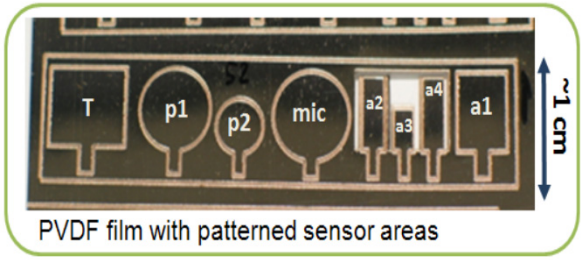


Light sensor



Pressure sensor

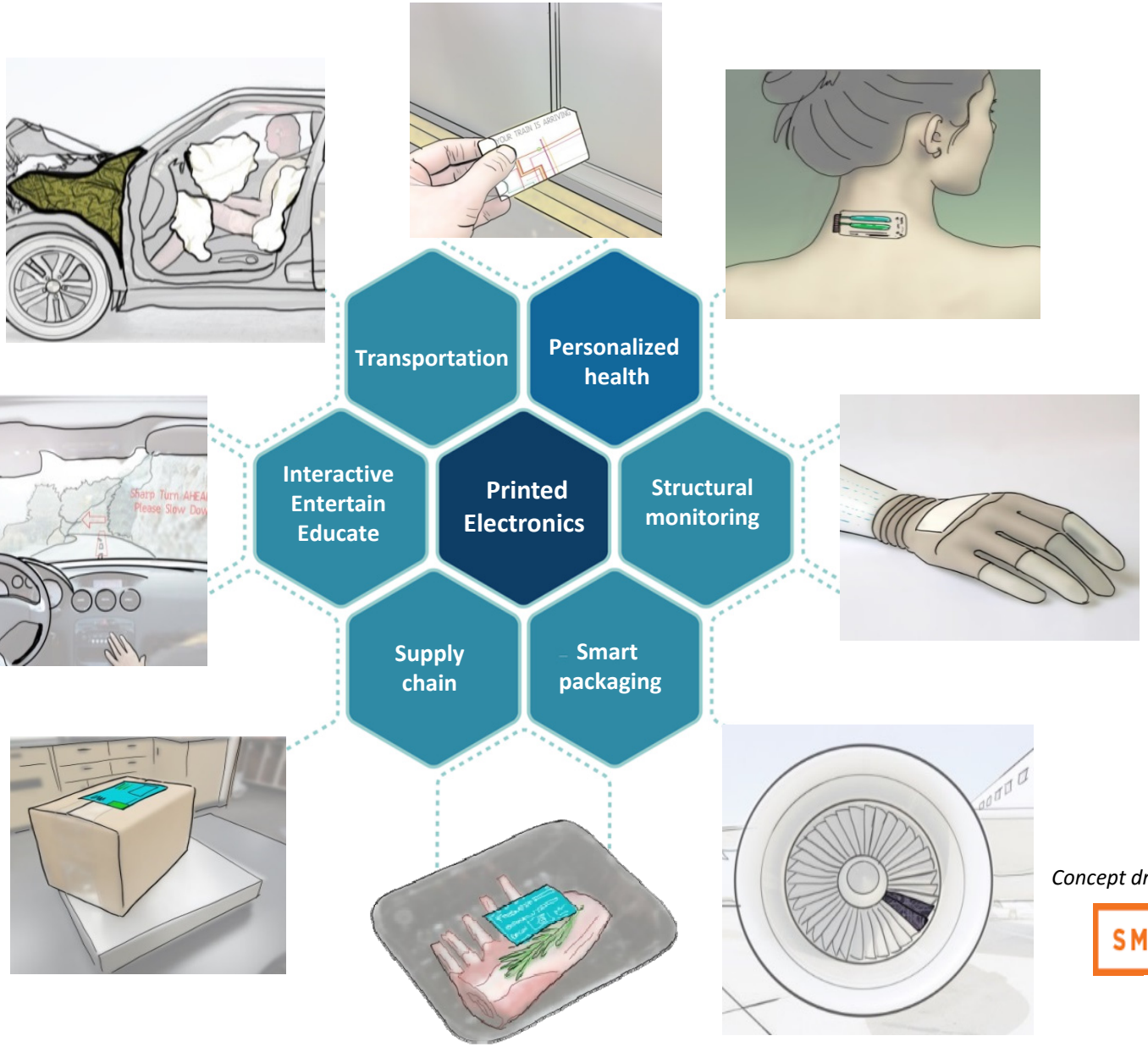
Flexible battery



Microelectromechanical Systems

parc
A Xerox Company

Printed electronics for IoE devices

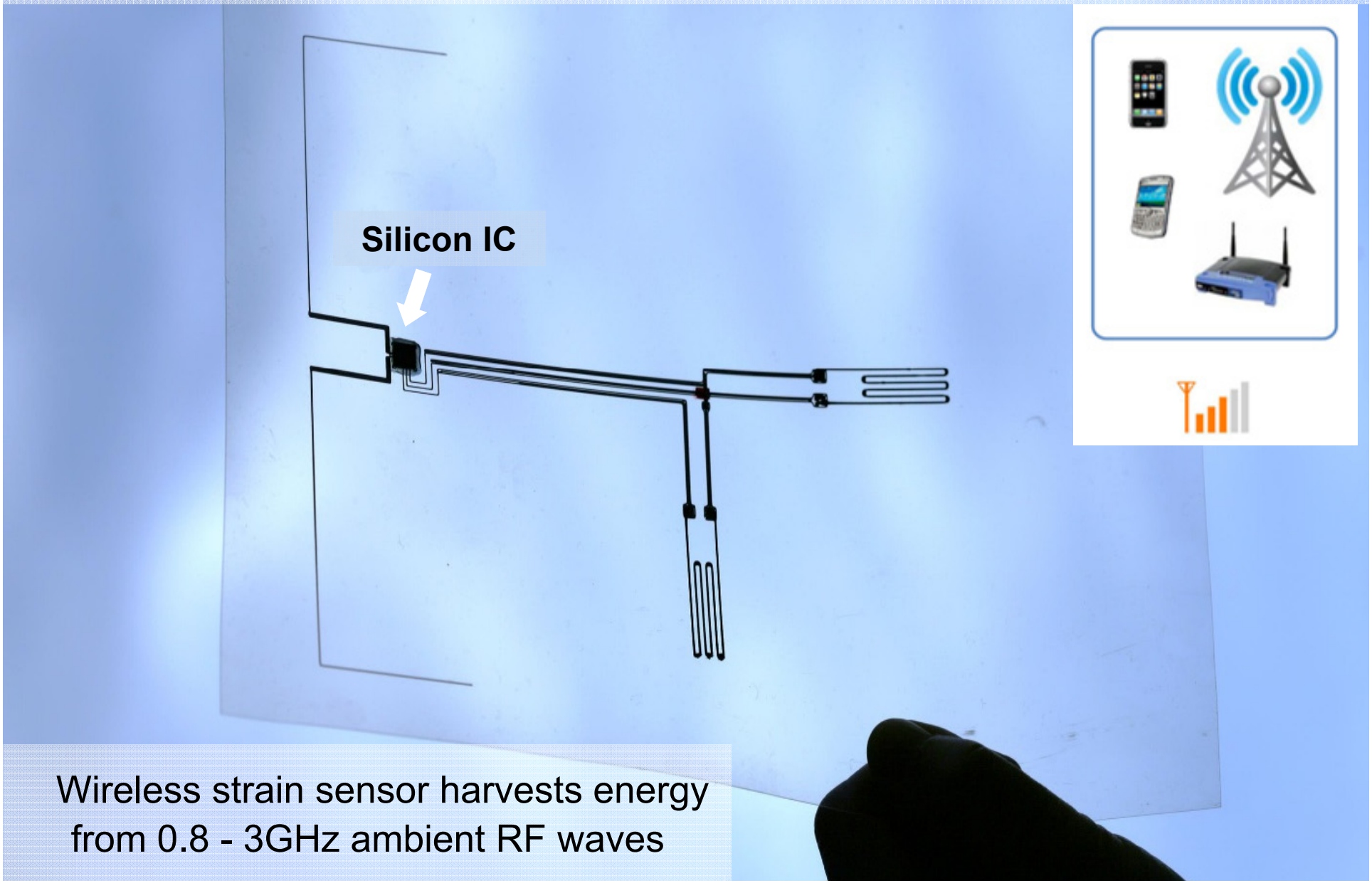


Concept drawings by Smart Design

SMART DESIGN

parc
A Xerox Company

For more performance, add Silicon:
Hybrid Electronics



Wireless strain sensor harvests energy from 0.8 - 3GHz ambient RF waves

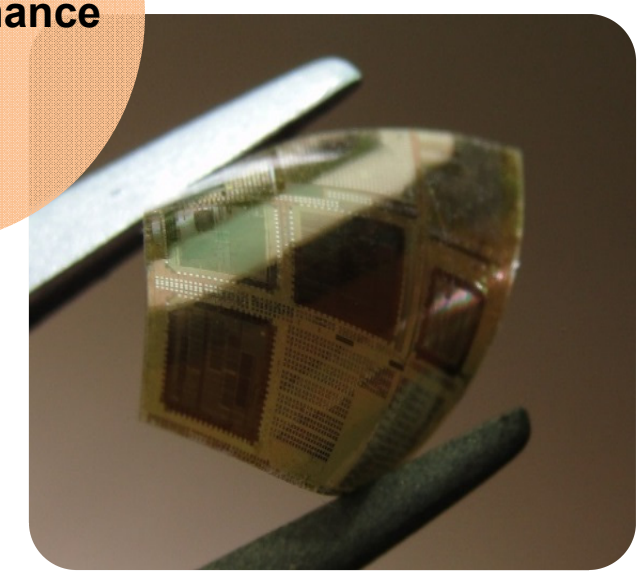
Flexible hybrid electronics manufacturing ecosystem

Intersection of the **electronics** and **printing** industries

Flexible substrates, low-cost manufacturing

Flexible, thin high-performance chips

Low-cost integration and assembly



NEXTFLEX

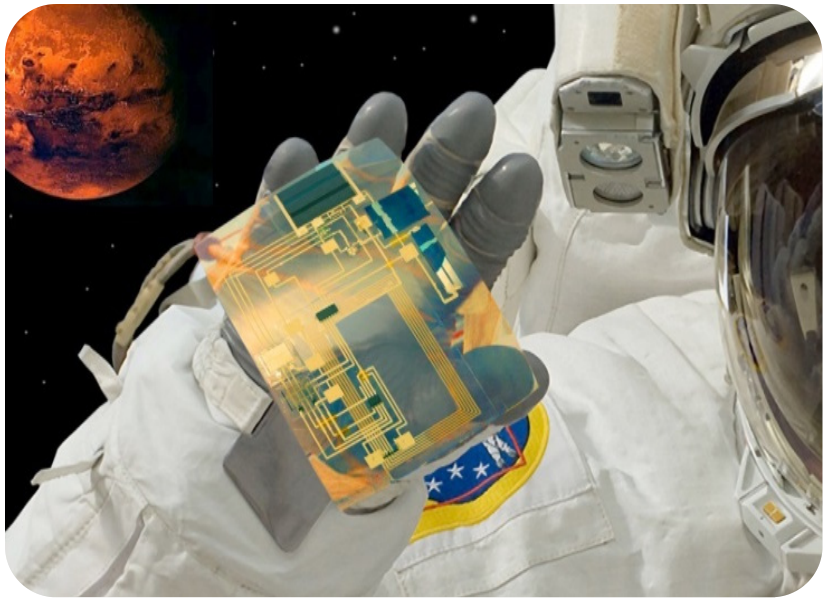
America's Flexible Hybrid Electronics Manufacturing Institute

Established: **2015**
Lead: **FlexTech Alliance**
Hub Location: **CA**

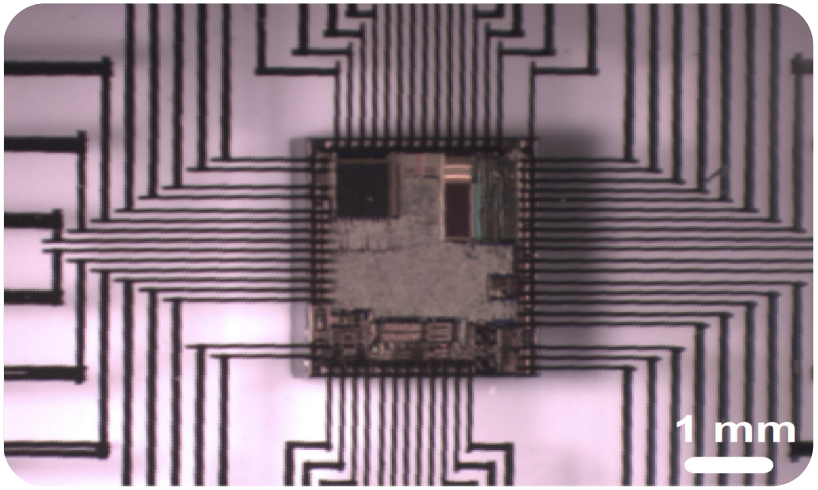
Members: **160+**
Federal Funding: **$75M**
Cost Share: **$108M**

Hybrid electronics prototypes

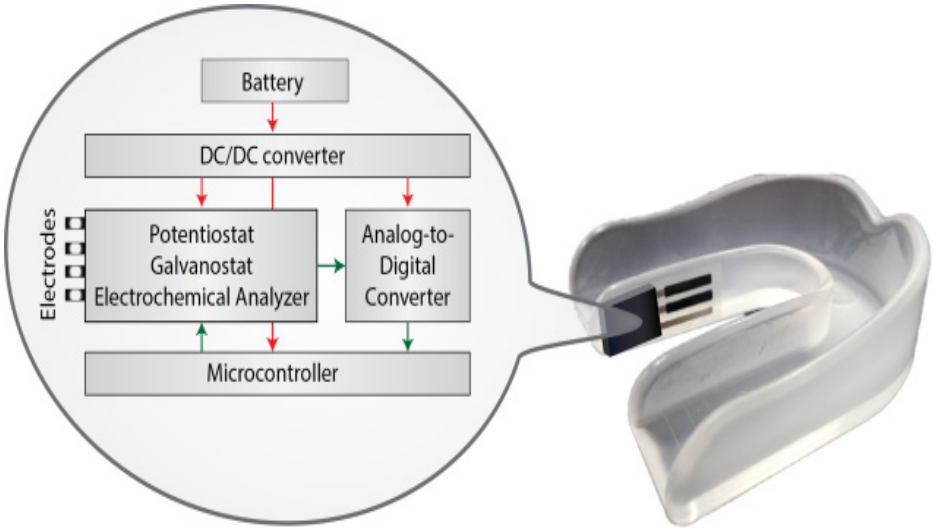
Embedded pressure sensor



On-demand printing



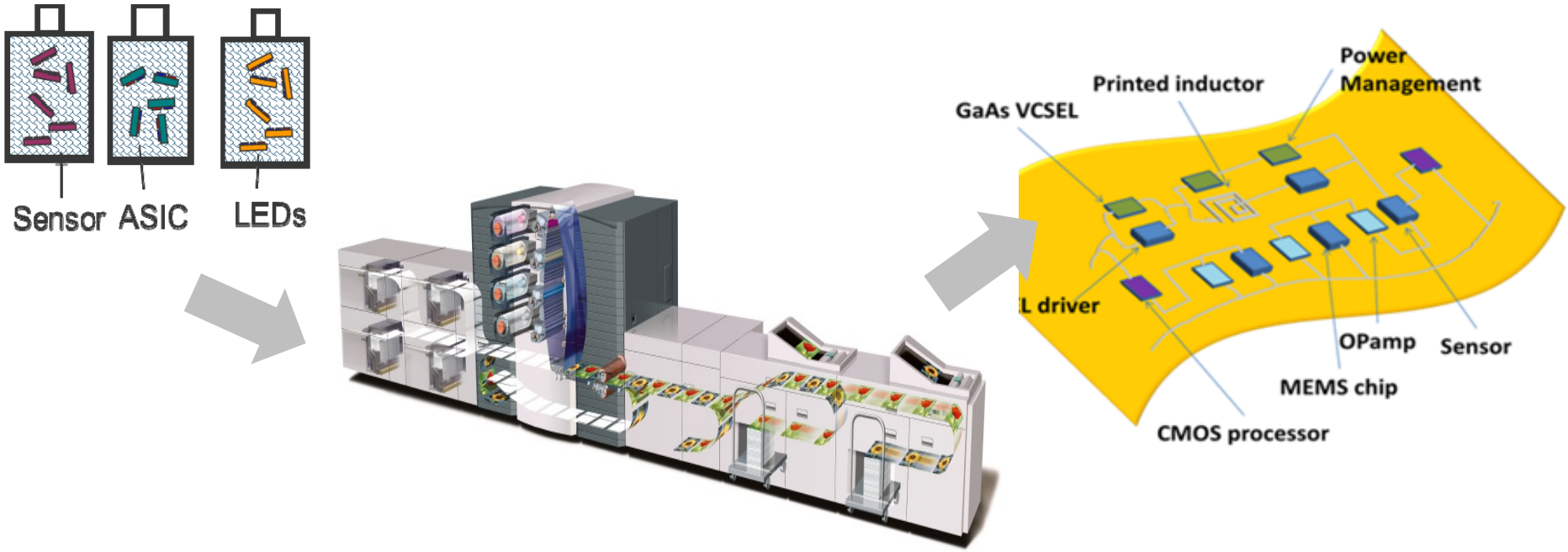
Bare Silicon die with printed connections

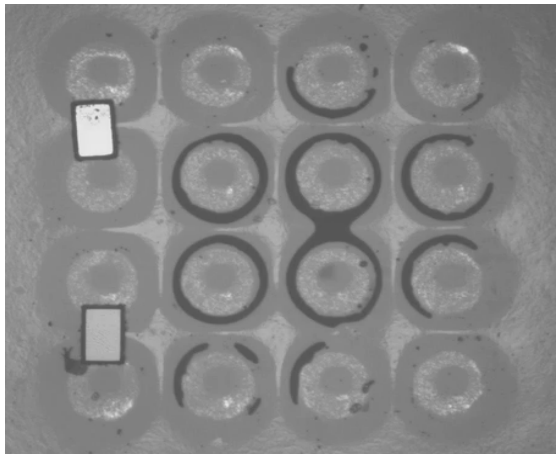


Mouth guard glucose sensor

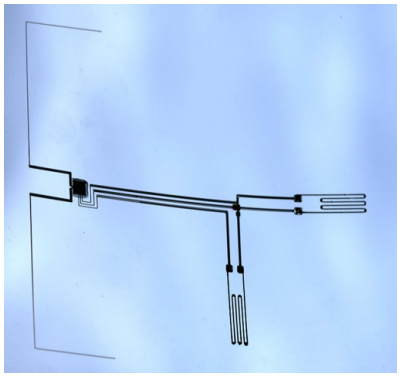
parc
A Xerox Company

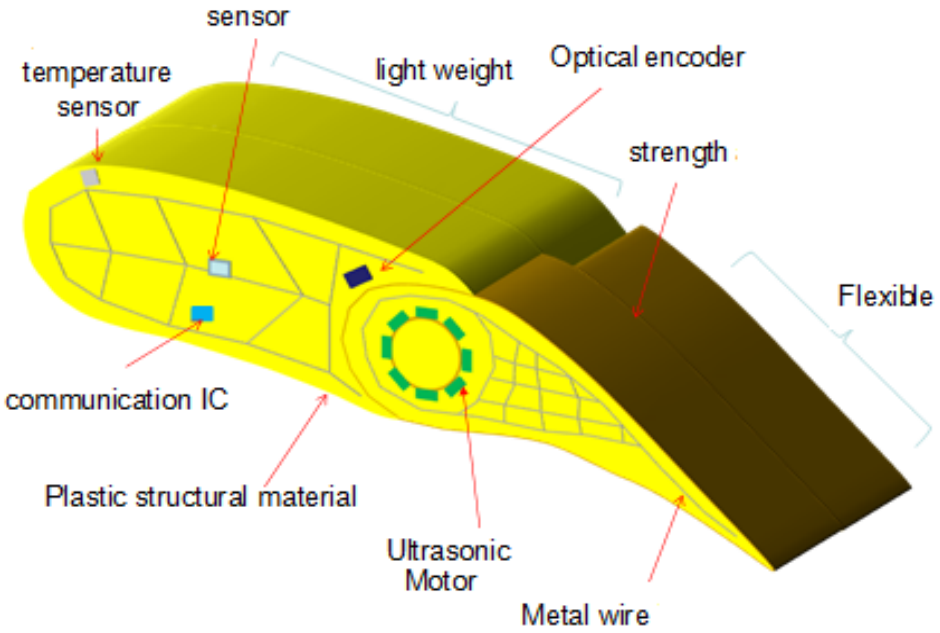
Breakthrough: Microchip ink printing





Smart Everyday Objects roadmap



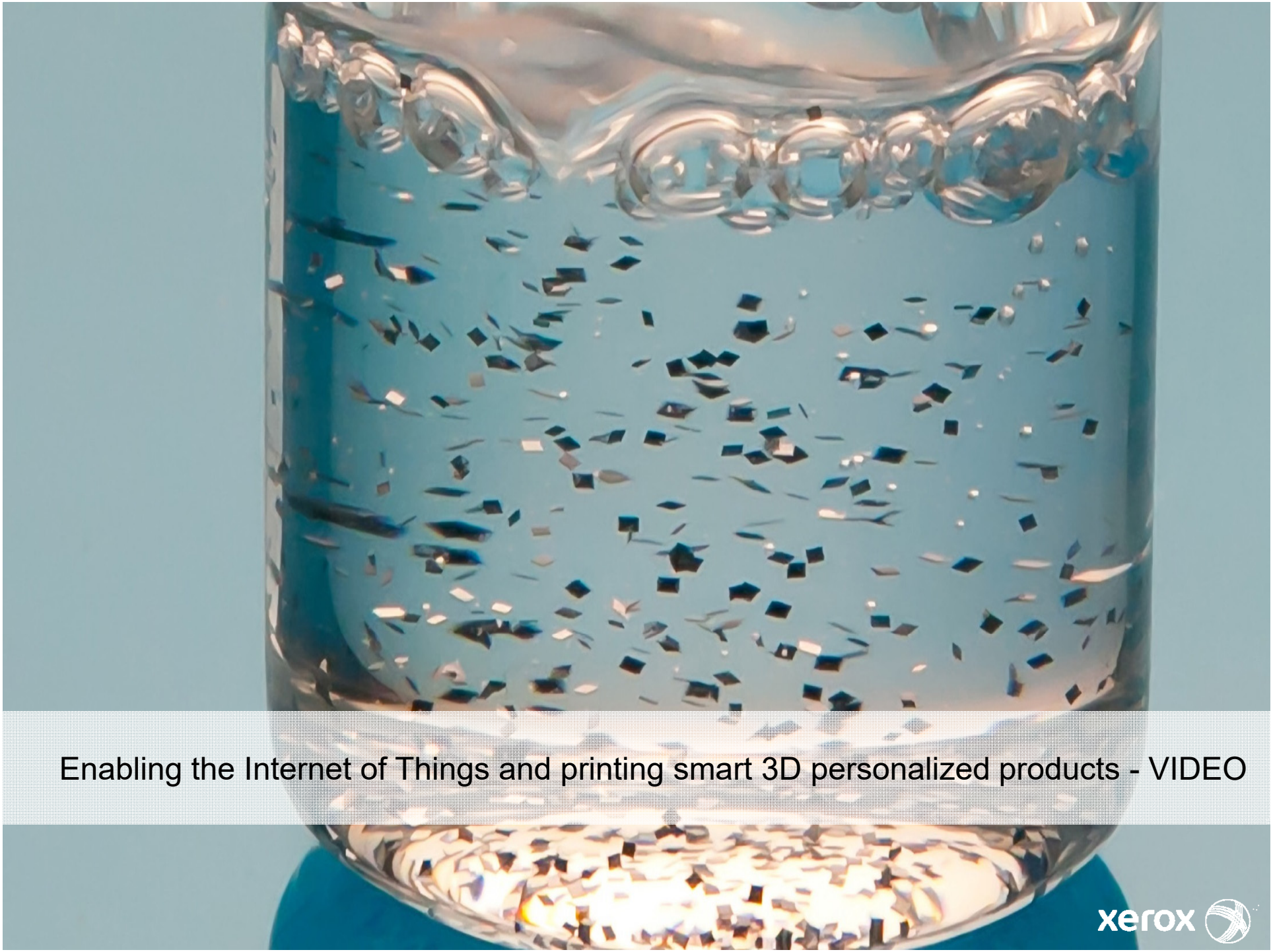


Integrated Circuits

Hybrid Electronic Devices

Integrated 3D Smart Everyday Objects

Time

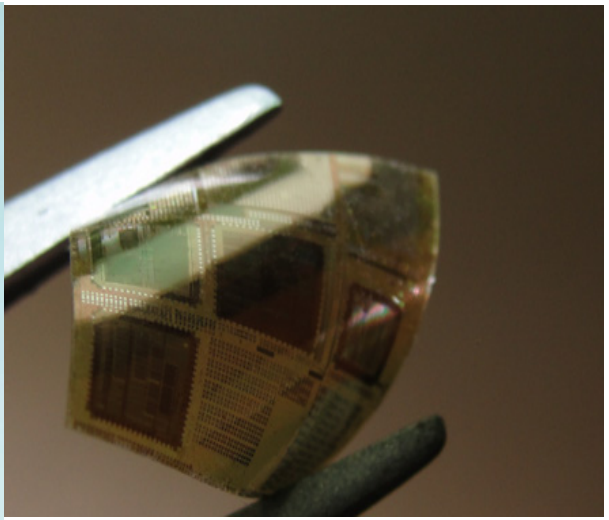


Smart Everyday Objects pose unique challenges for the ISSCC community

Any form factor, robust, flexible

Performance and functionality on-demand

Low cost and ultra-low power



Ana Arias, UC Berkeley

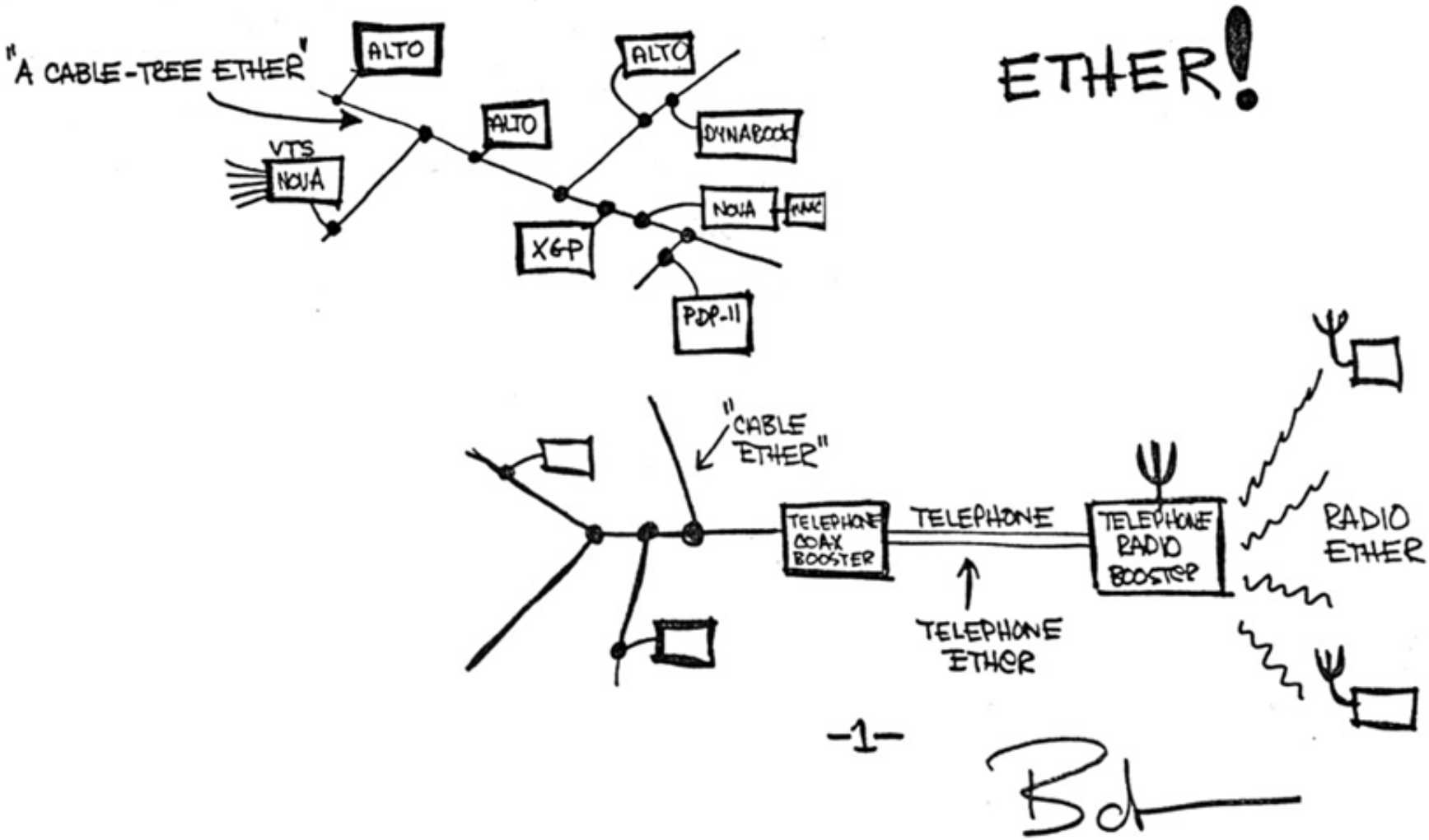
Outline

1. Smart Everyday Objects

2. Information-Centric Networks

3. Automated Real-Time Insights

Network protocols are **over 40 years old**



Bob Metcalfe's 1972

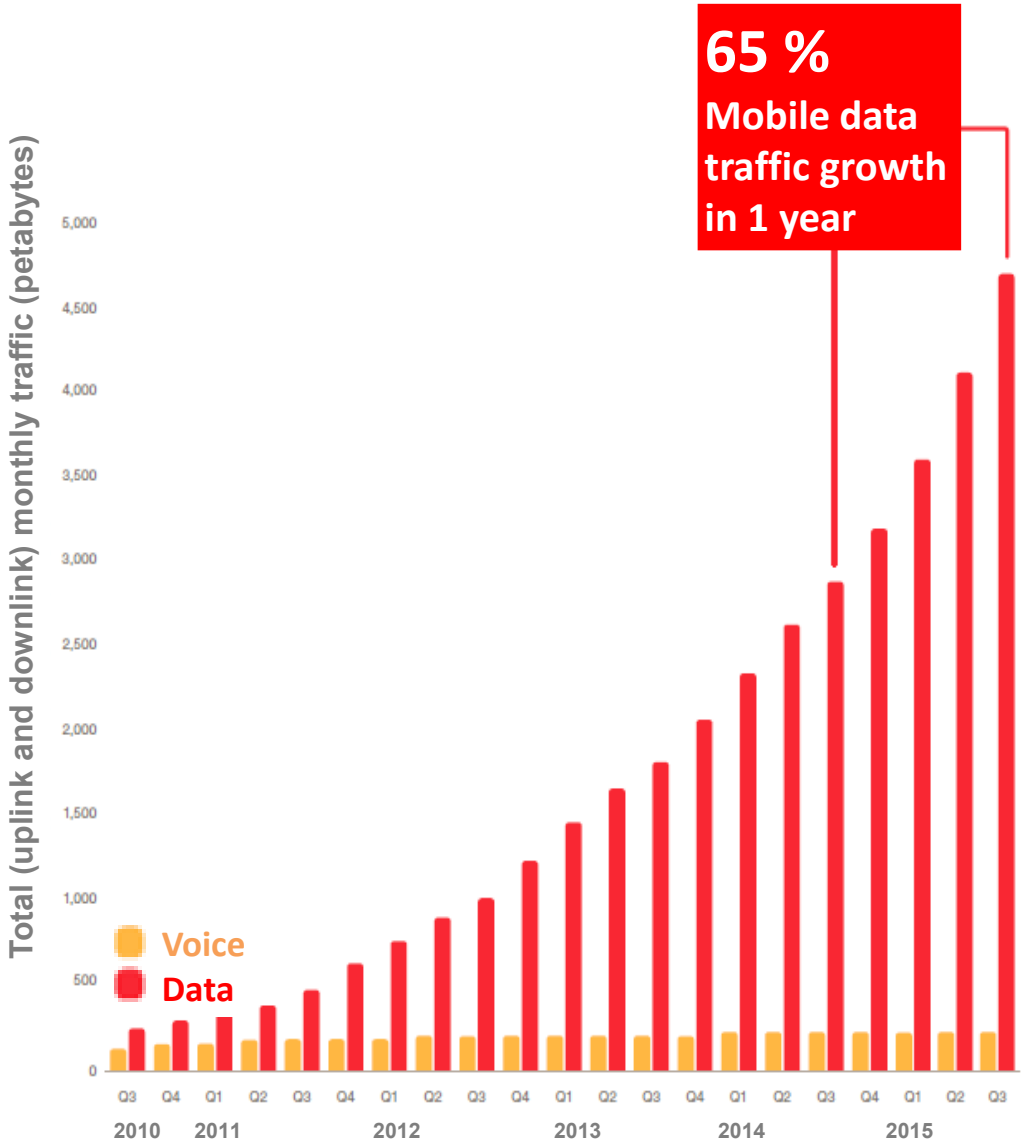
original sketch of his "*Ethernet*" vision at PARC

The Internet is significantly challenged

Connections
- billions of mobile devices
- trillions of IoE objects

Content
- video
- sound
- huge volumes of diverse sensor data

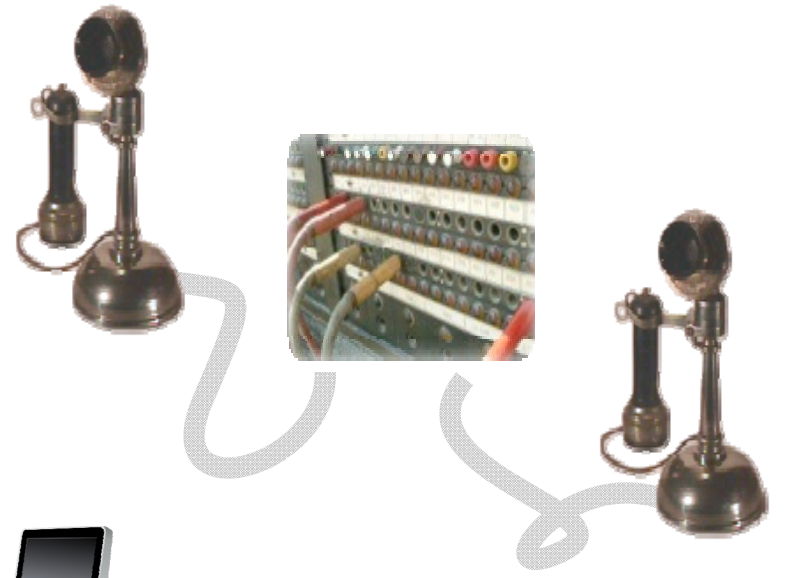
Issues
- reliability
- security
- privacy



Ericsson

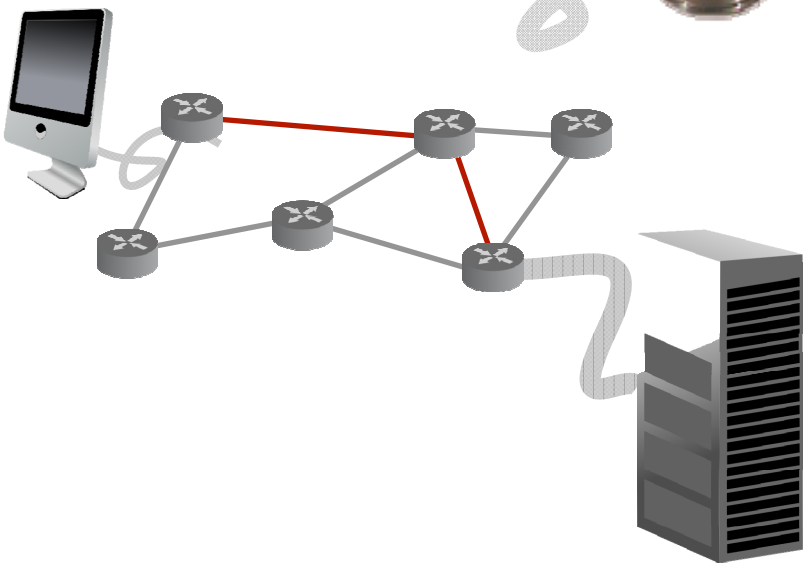

SAMSUNG
BABY MONITORS HACKED
FOCUS
HOW DO HACKERS DO IT?
abc 2

Internet mirrors phone connection



1876

1-650-812-4472

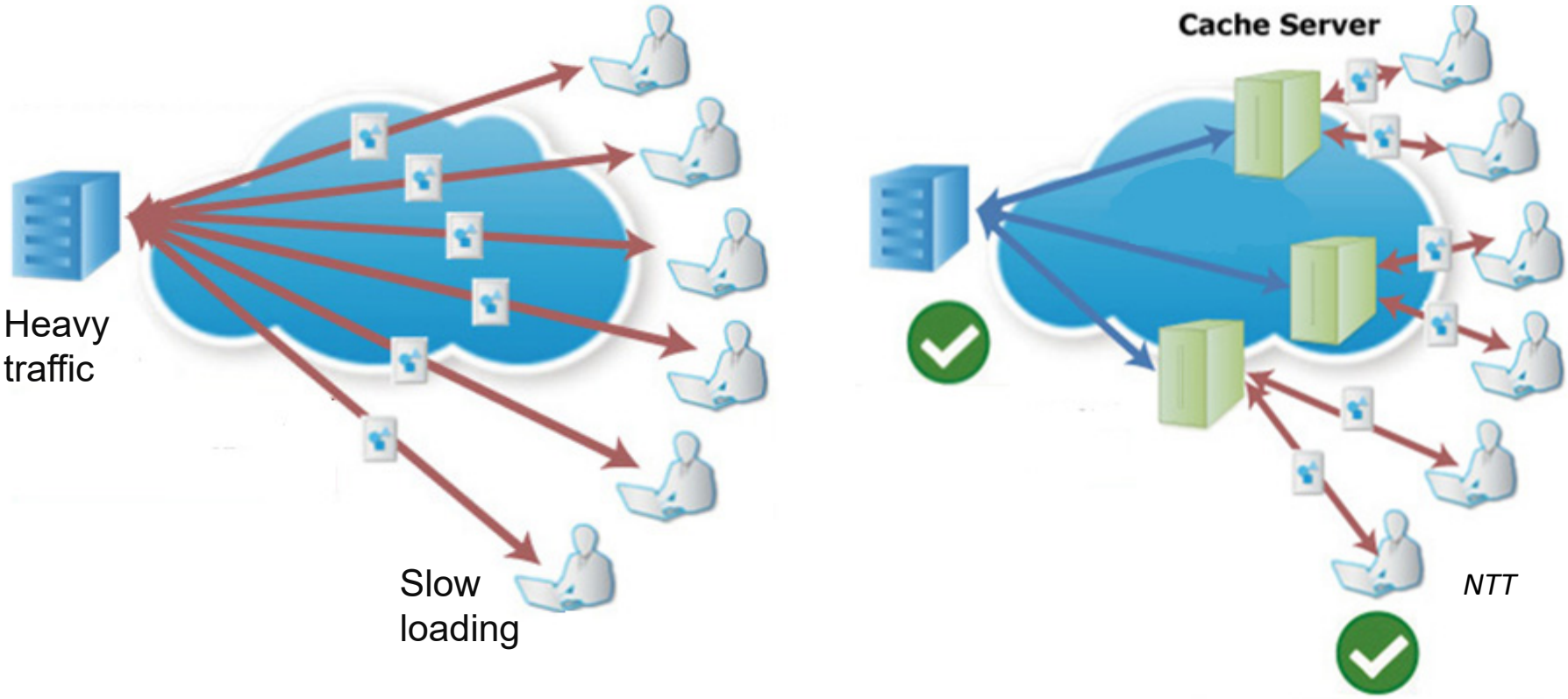


2015

170.124.100.133

Point-to-point communication

Band-Aid: Content Delivery Networks

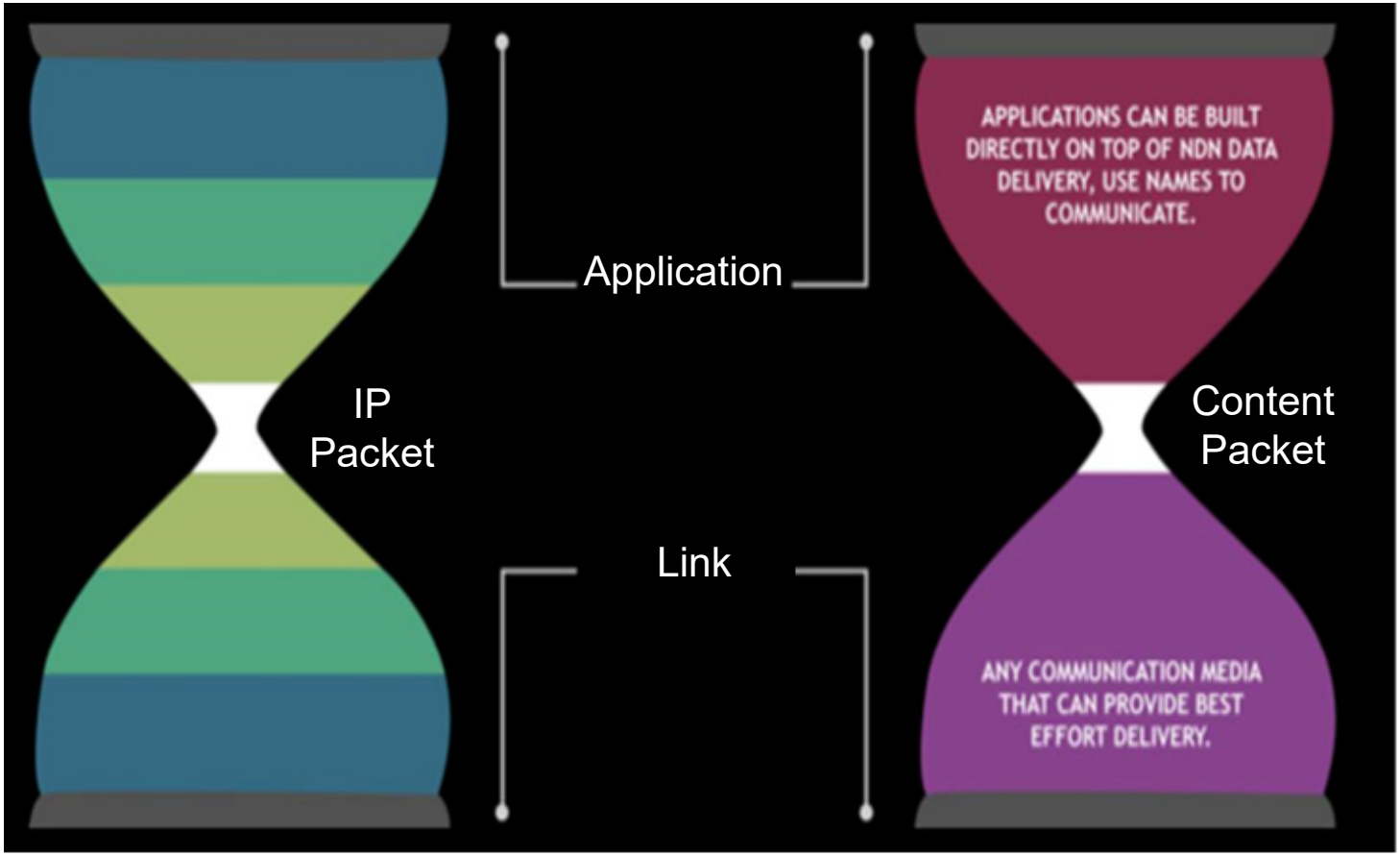


In addition, the U.S. National Science Foundation funds several next-generation Internet architecture programs

Breakthrough: Information Centric Networking (ICN)

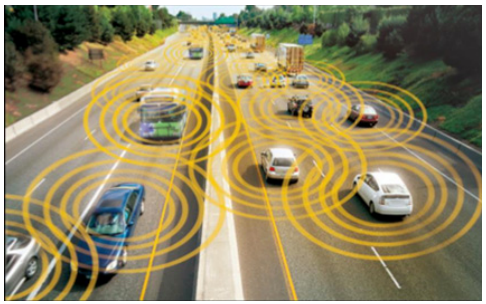
Content accessed by **name** *not* the **IP address** where it resides

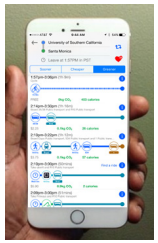
- Content Centric Networking (CCN) led by PARC
- Named Data Networking (NDN) led by UCLA



Lixia Zhang, UCLA

Designed for secure **content** delivery





Interest
request

I

C

Content
reply

NETFLIX

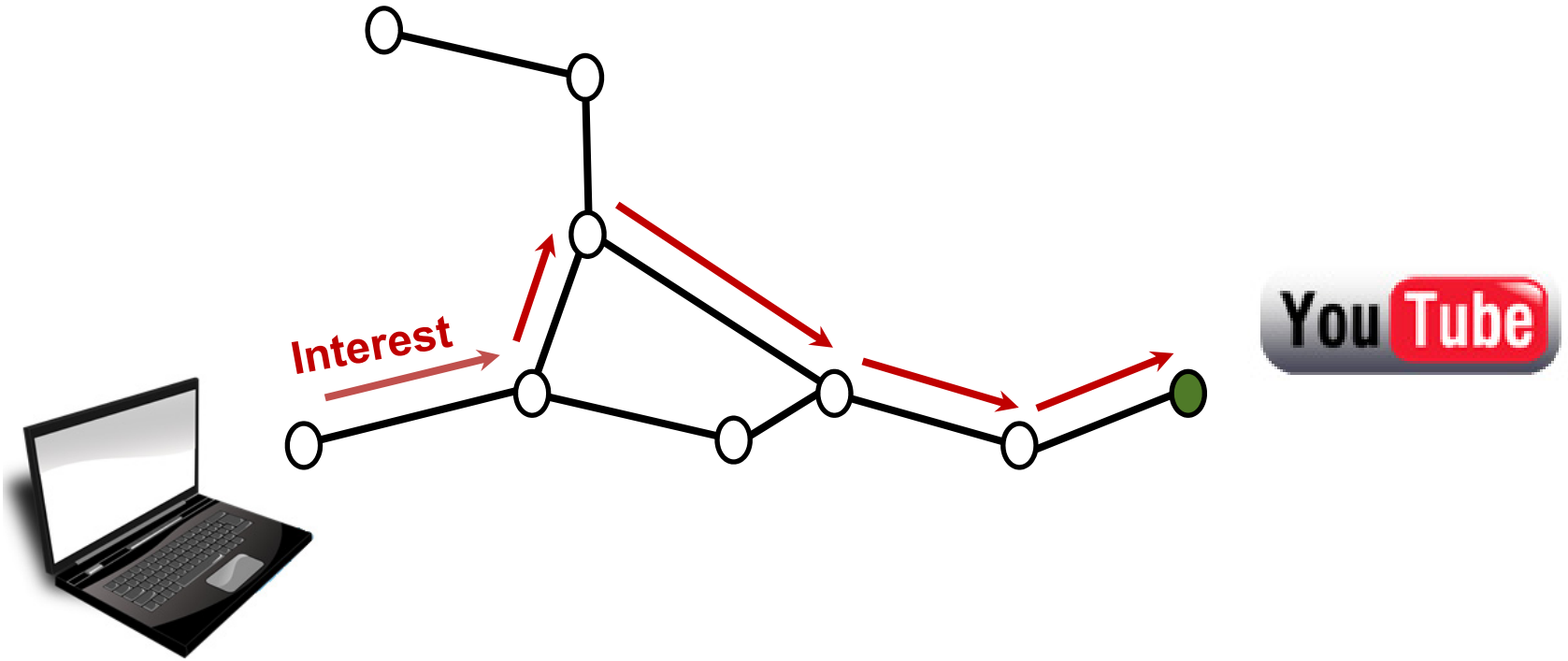
YouTube

Consumer

Producer

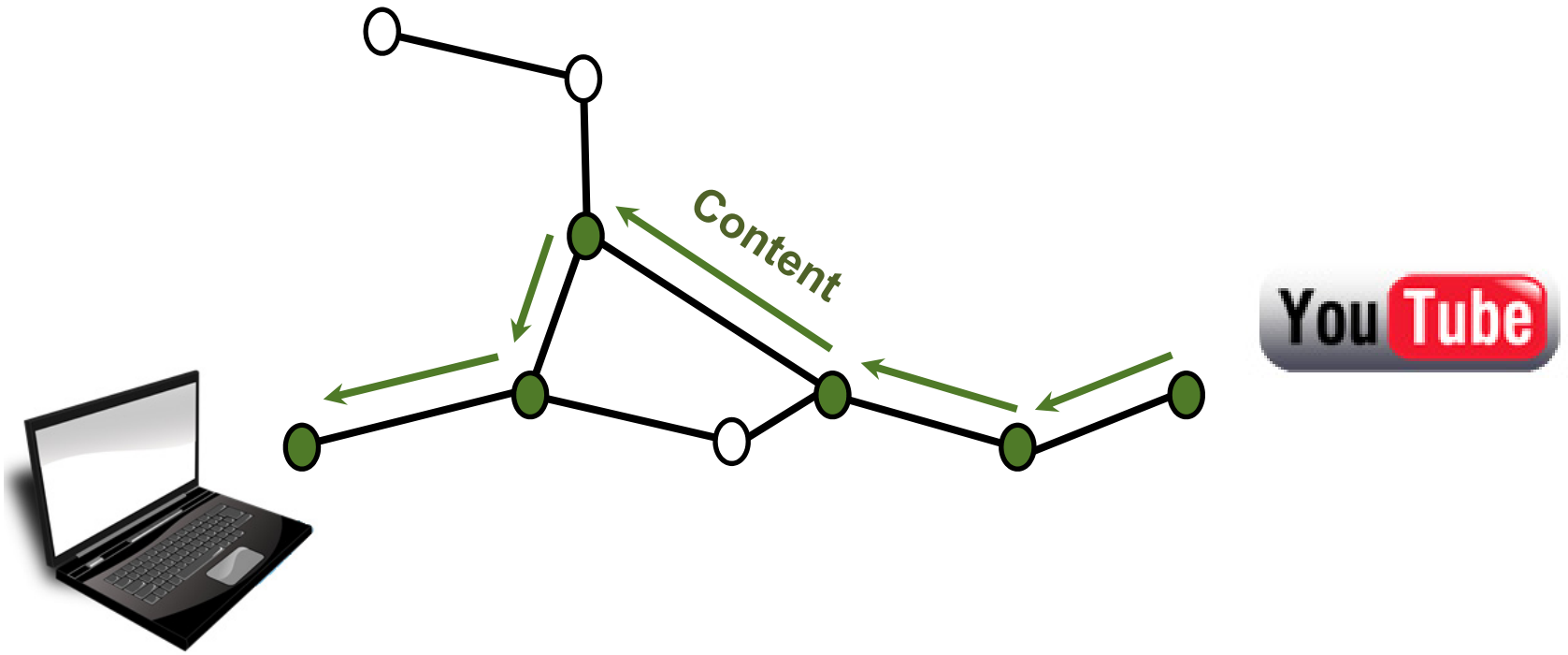
Content is **named, authenticated** and **encrypted**

Interest request routed to content producer

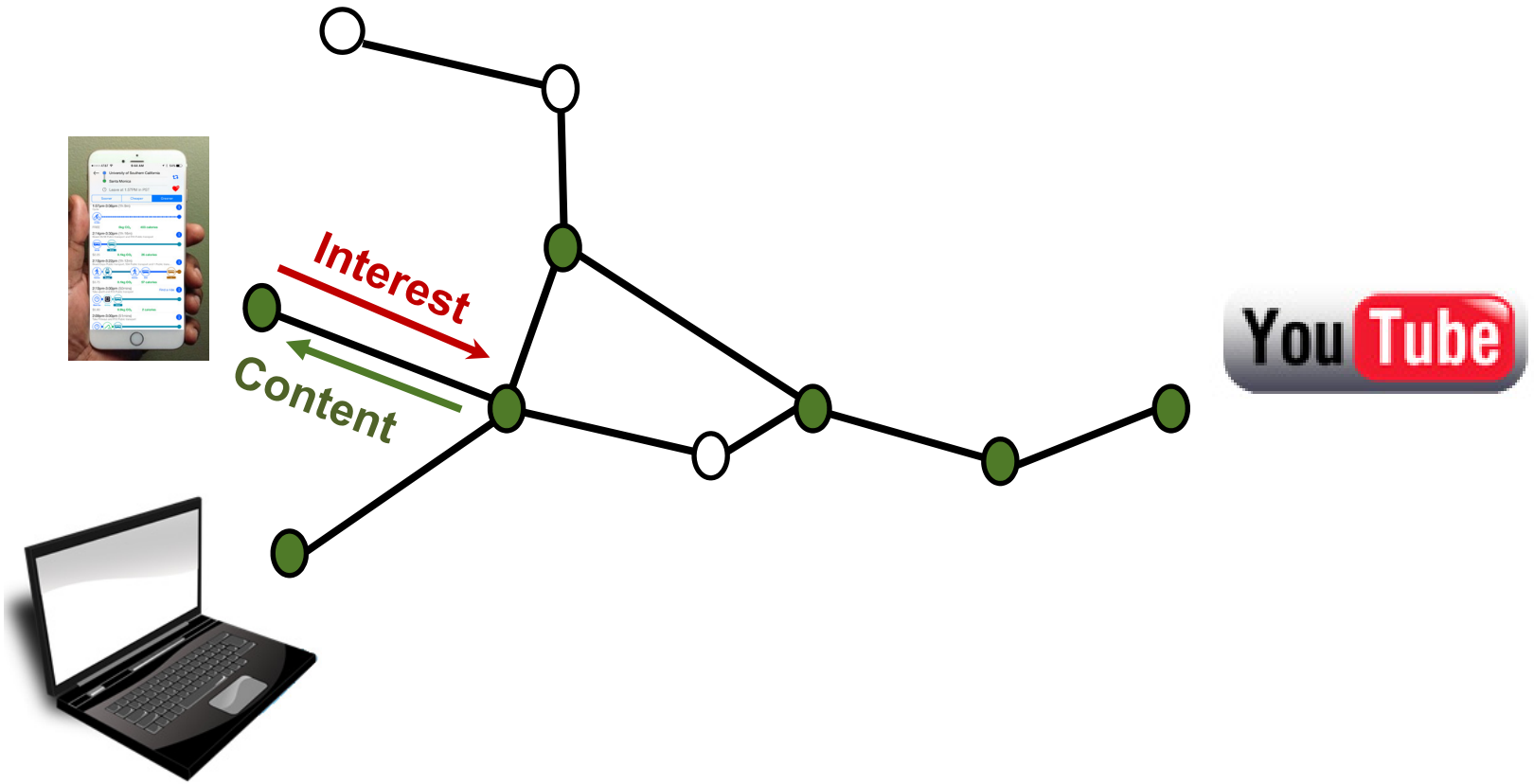


Router

Content follows reverse path and **is stored** along the way in network routers



Stored content fulfills additional requests



Simple, fast, efficient, secure and **authorized** retrieval of content

Targeted for intercept with **5G** Mobile Technology

Information centric routers pose **unique IC challenges**

Cisco

Routers will require **significant memory** and **processing power.**

More Silicon!

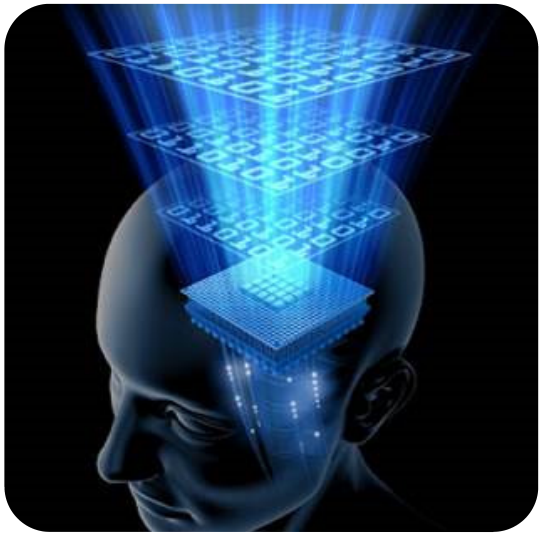
	Today's IP routers	Future ICN routers?
Memory	**"as little as possible"** < 1 Gigabyte switching buffer	**"as much as possible"** >> 10 Terabyte content storage **>> 10,000 more memory**
Switching Speed	< 100 clock cycles per IP packet	> 1,000 clock cycles per content packet **> 10x faster processors**

36

Outline

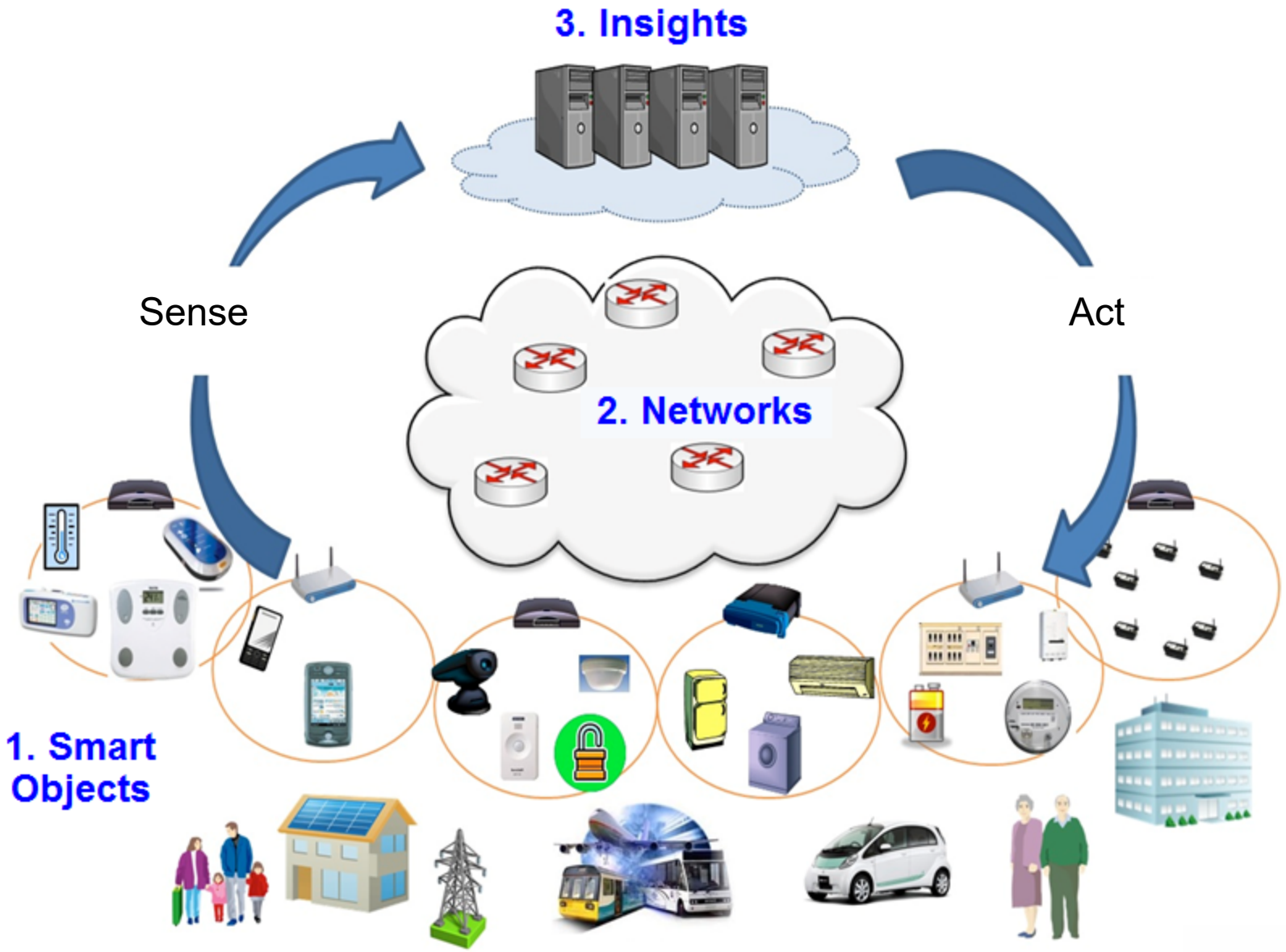
1. Smart Everyday Objects

2. Information-Centric Networks



3. Automated Real-Time Insights

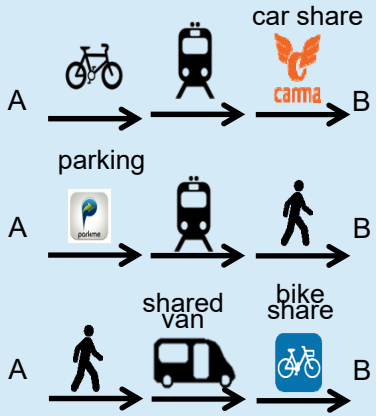
Real-time Insights: third pillar of the IoE

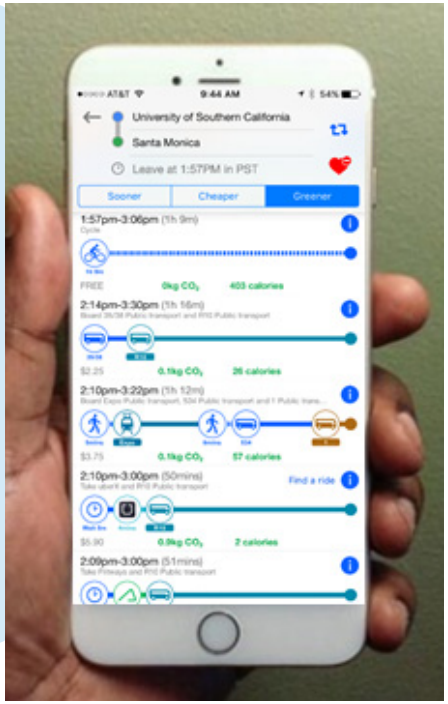


Real-time Insights for more livable cities

Citizens

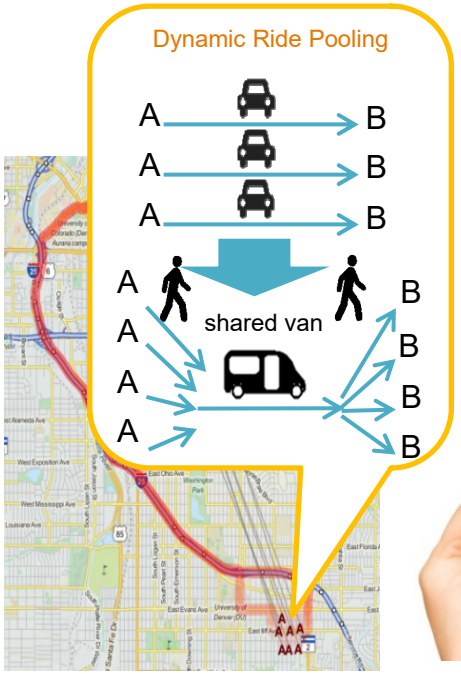
Multi-provider, point-to-point multi-modal trip Planning:

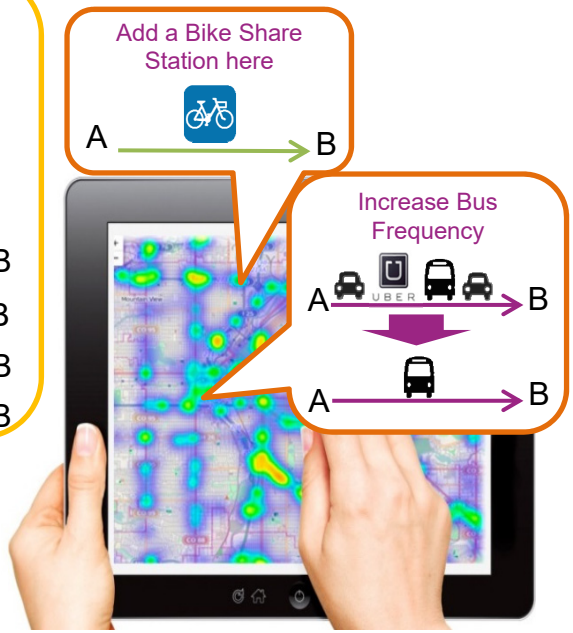




GoLA
Find Your Way in LA

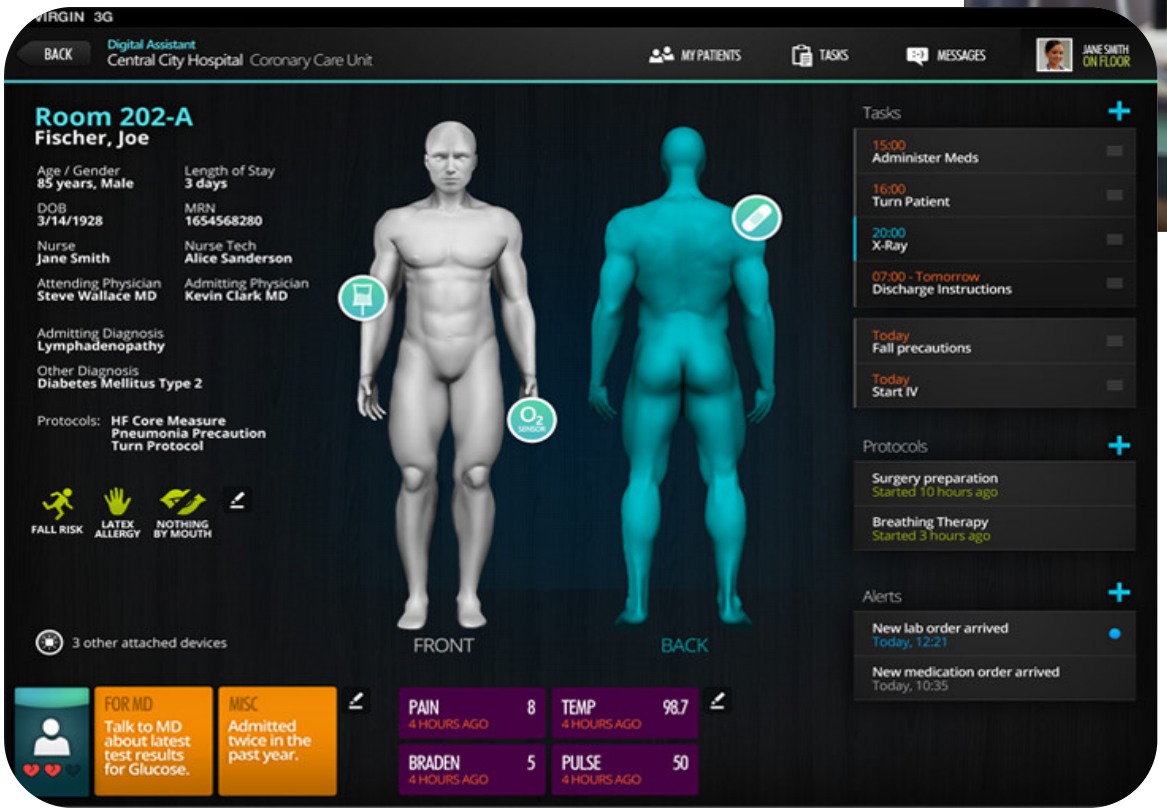
City Officials





Personalized trip planning and transportation optimization

Real-time Insights for better healthcare

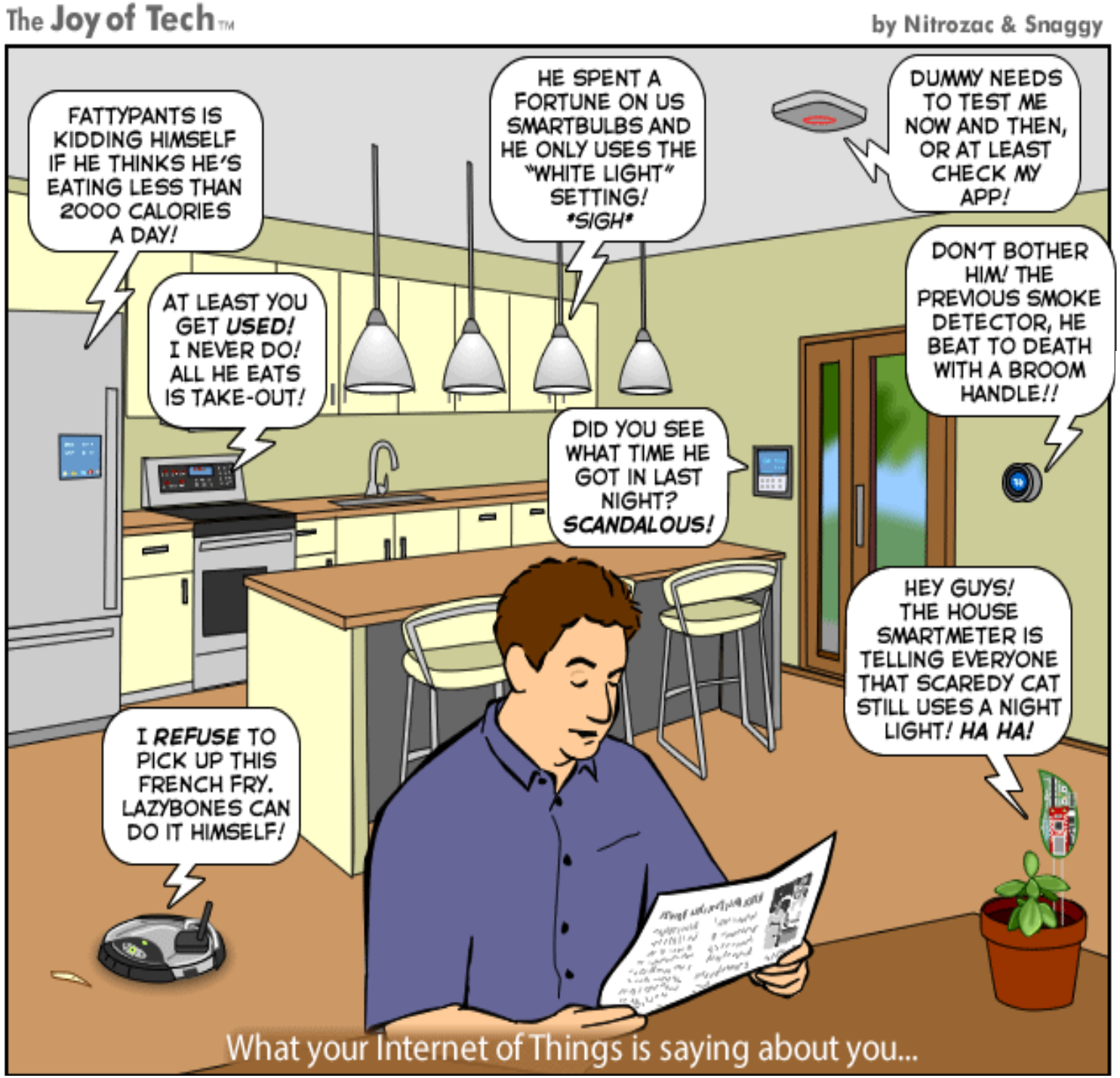


Personalized care and hospital optimization

No-touch measuring of vital signs and diseases

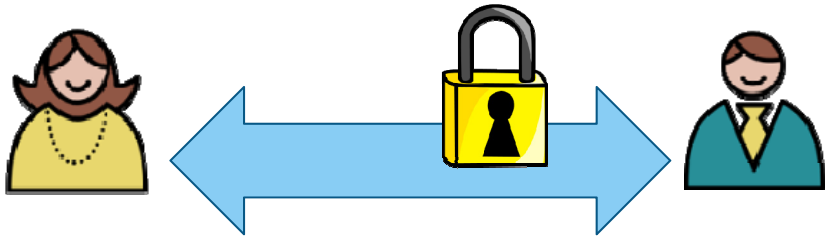

xerox

“Googling Reality”

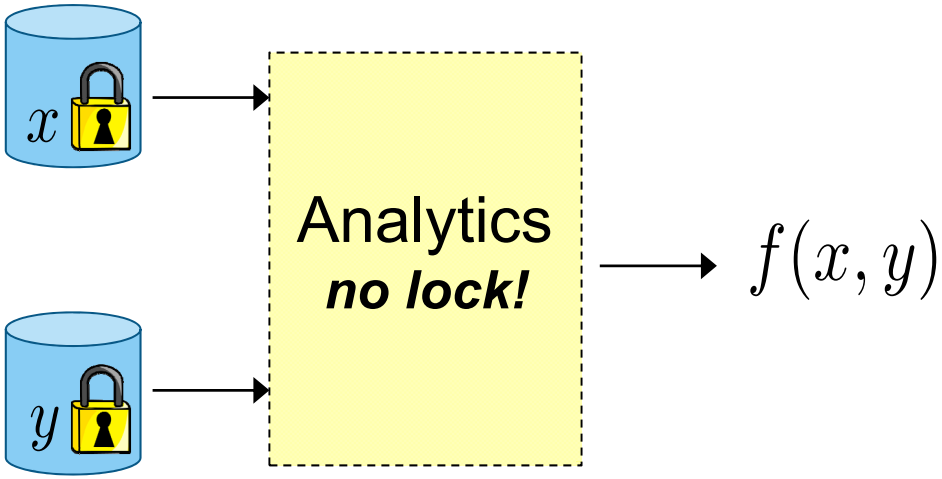


The end of privacy?

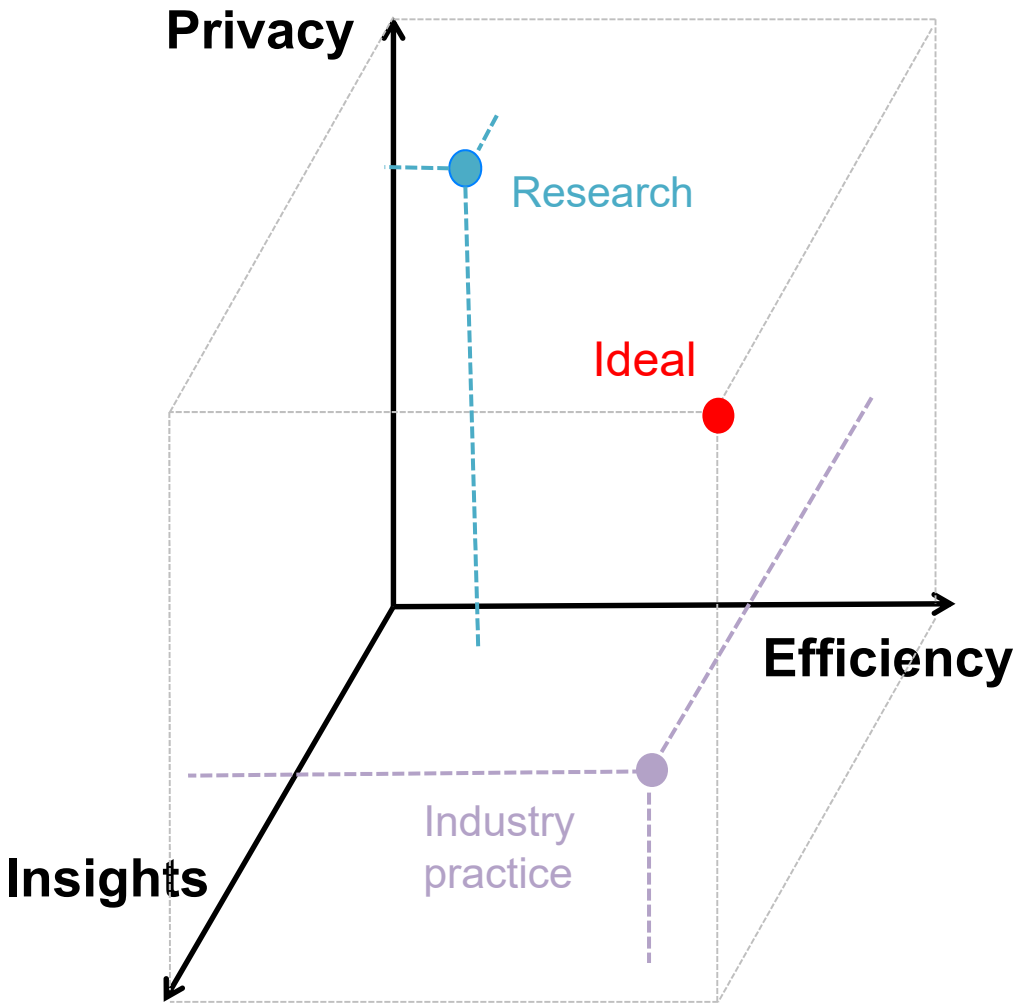
Data is private while **stored** or in **transmission**



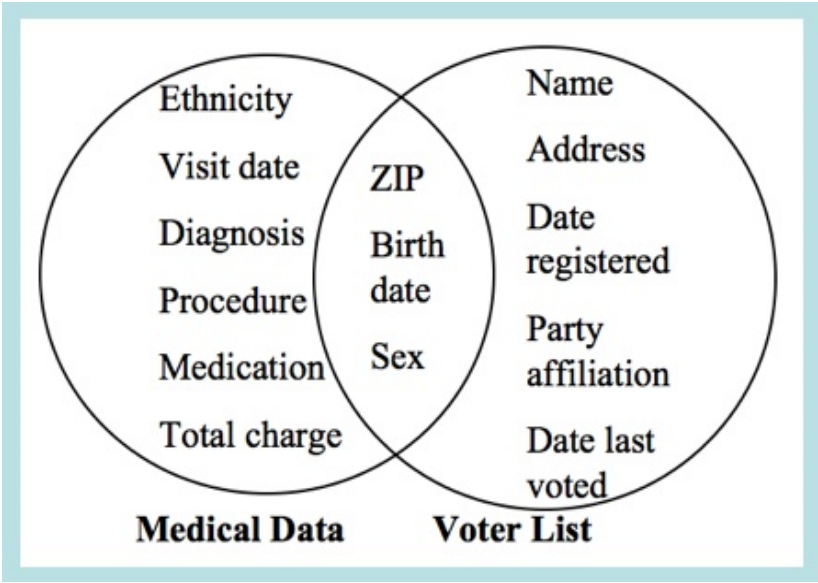
No privacy during analytics done by service providers



Privacy during analytics is a hard problem

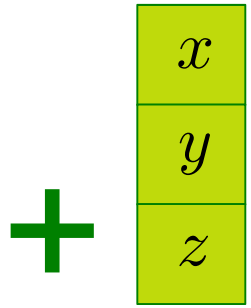


Anonymizing data not always secure

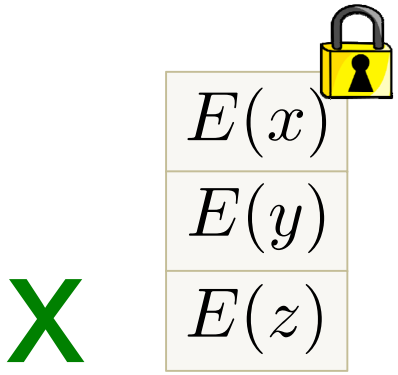


Latanya Sweeney, CMU

Breakthrough: Homomorphic Encryption



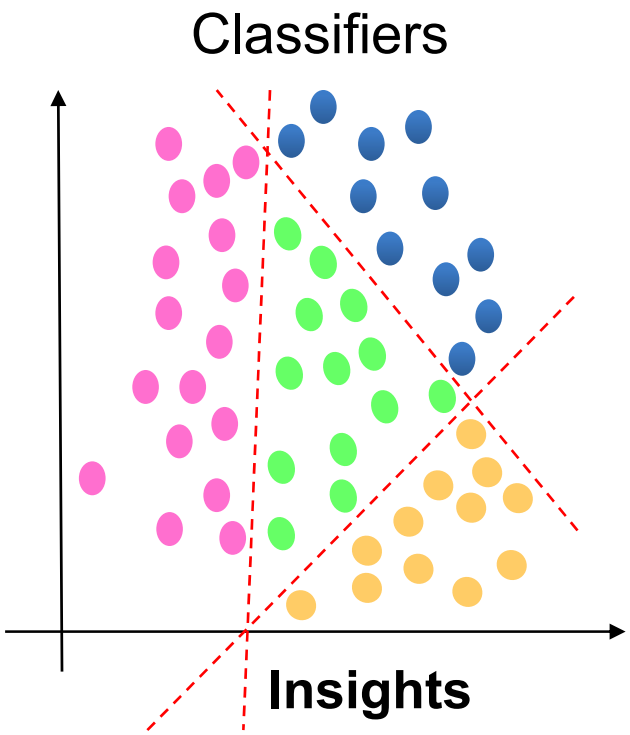
$$S = x + y + z$$

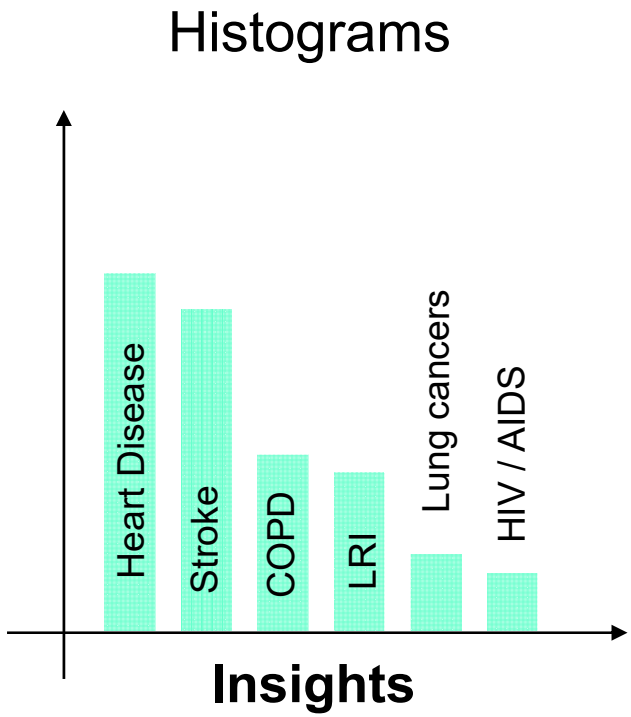


$$E(S) = E(x)E(y)E(z)$$
$$= E(x + y + z)$$

Even the simplest of calculations using the cipher text is a million times **slower**

Getting insights from data without seeing the data





COPD: Chronic Obstruction Pulmonary Disease
LRI: Lower Respiratory Infection

Significant **processing power** and **storage** required

More Silicon!

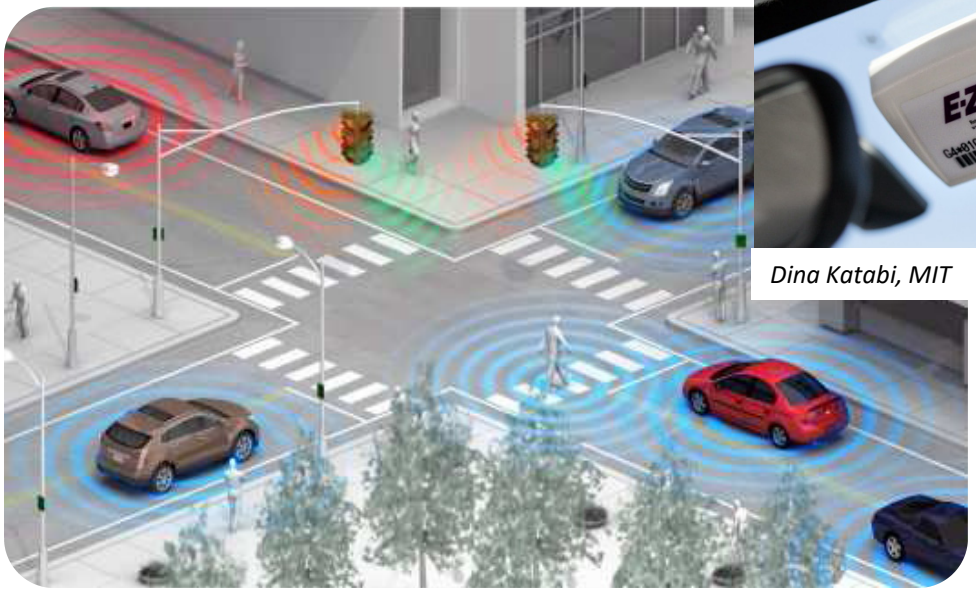
parc
A Xerox Company

Privacy by moving analytics to the “Edges” of the IoE

Selectively share insights with service providers in the cloud

Real-time insights at the edge for transportation

minimize congestion
improve safety



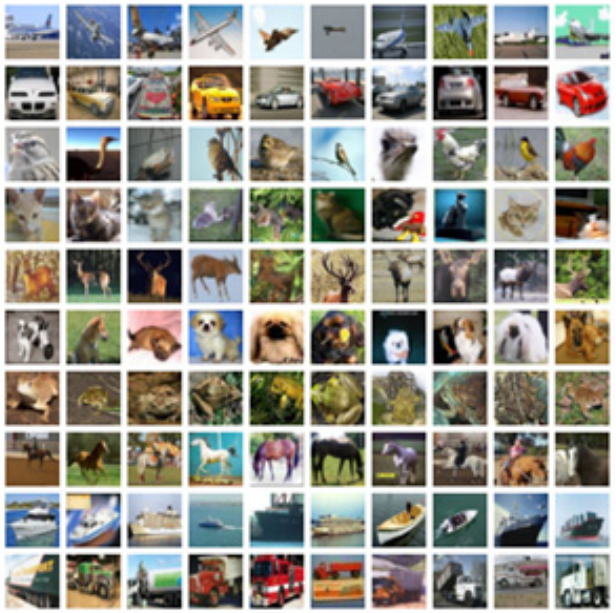
Dina Katabi, MIT

Machine Learning helps cameras **"see"**

Machine Learning

Plane
Car
Bird
Cat
Deer
Dog
Frog
Horse
Ship

Significant **engineering time** and **domain expertise**

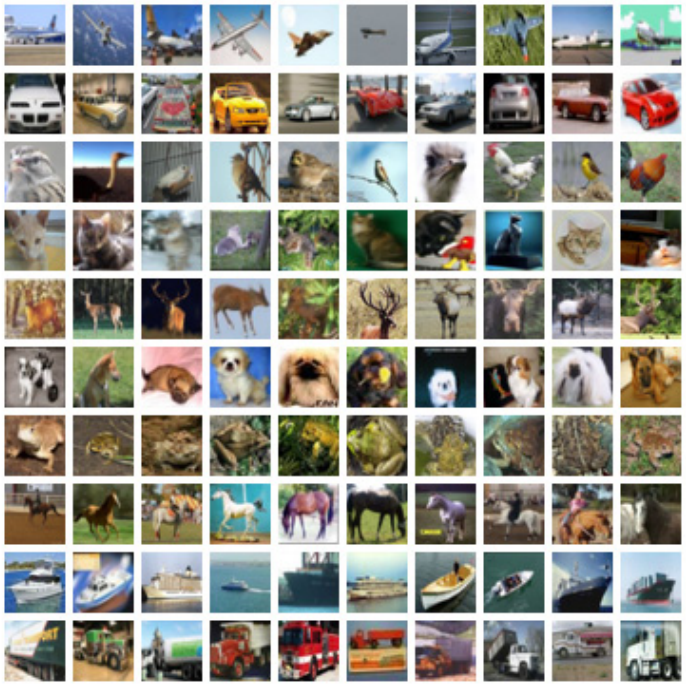


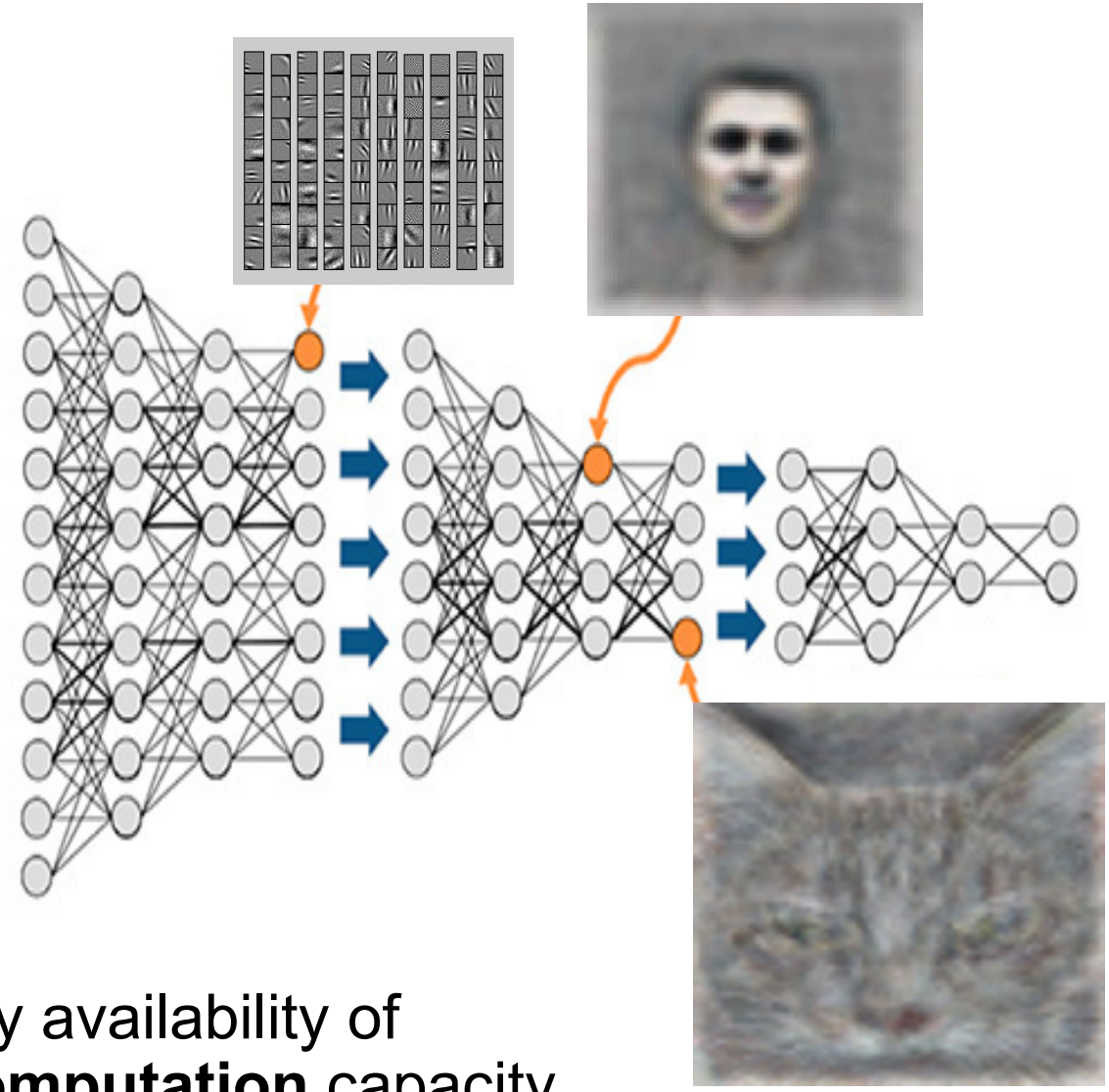
Machine Learning algorithms with expert-designed features

Supervised learning with labelled images

Fei Fei Li, Stanford U.

Breakthrough: **unsupervised** deep learning

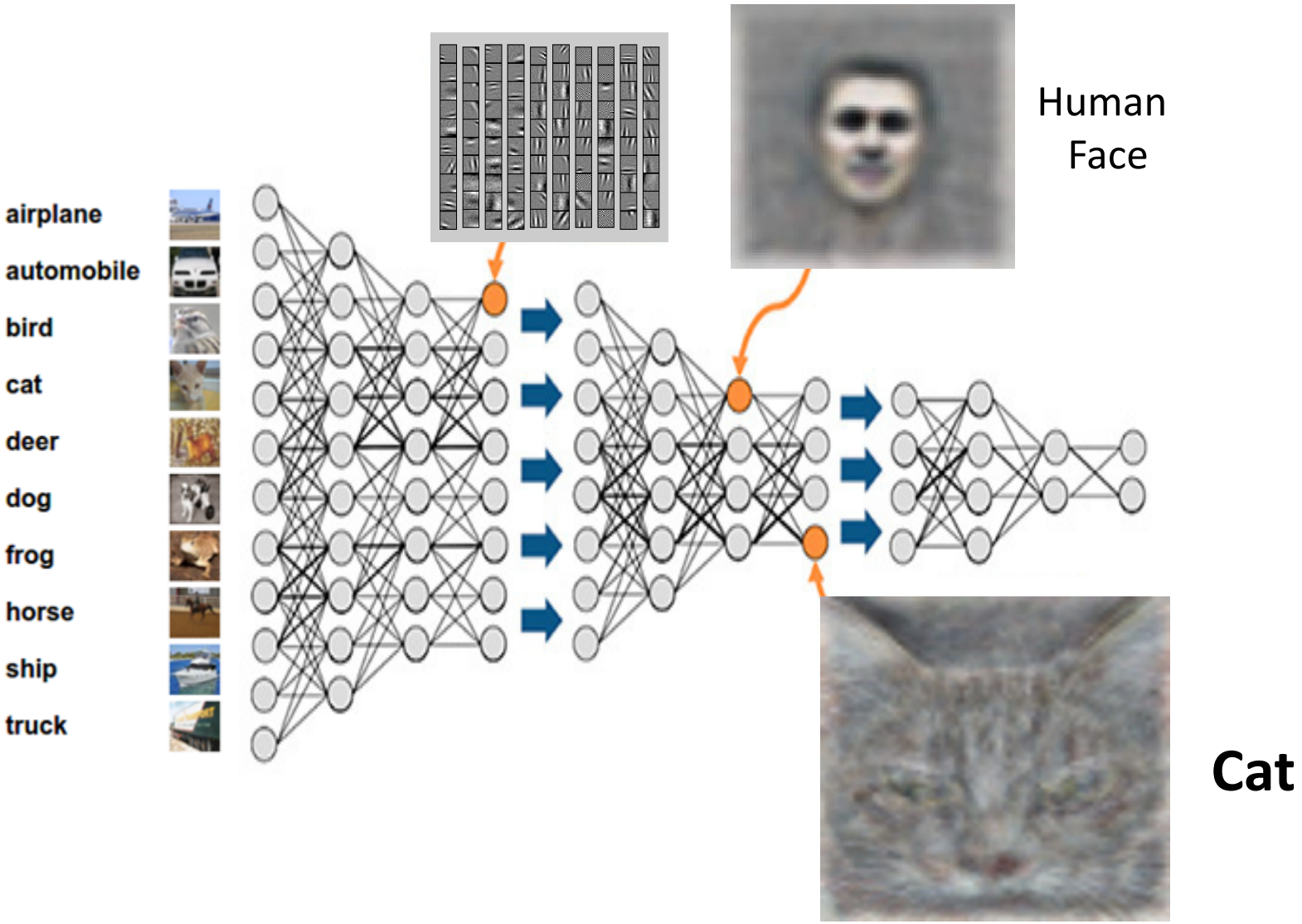


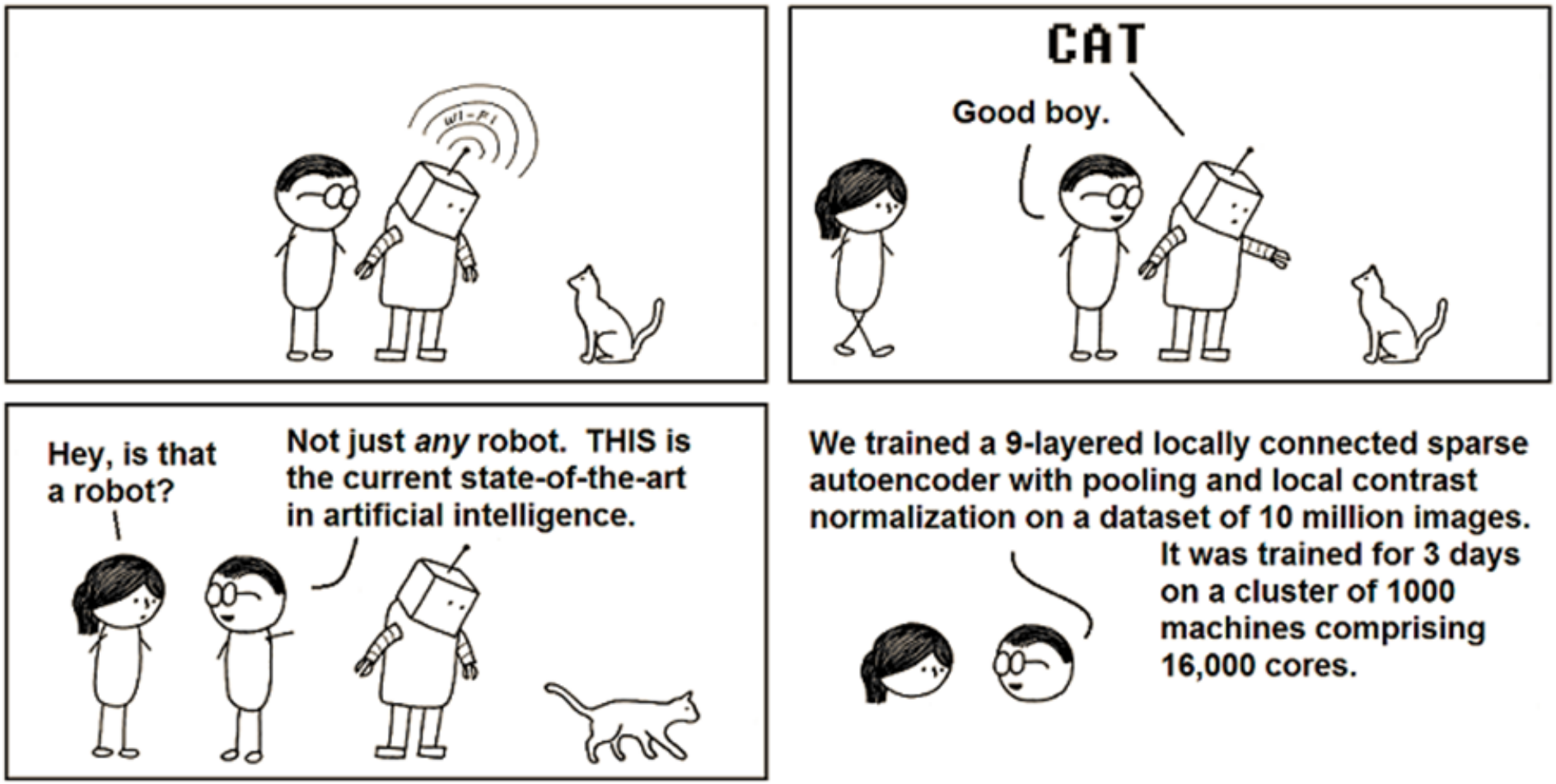


Enabled by availability of
big data and **computation** capacity

Google

Fine-tuned with supervised deep learning



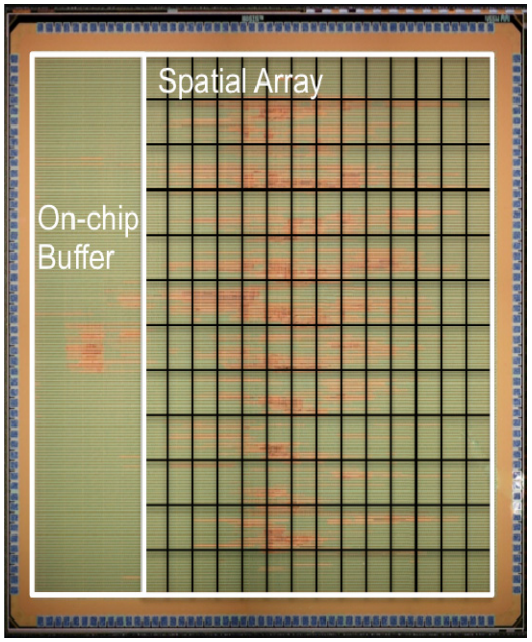


More Silicon!

Abstruse Goose Cartoon

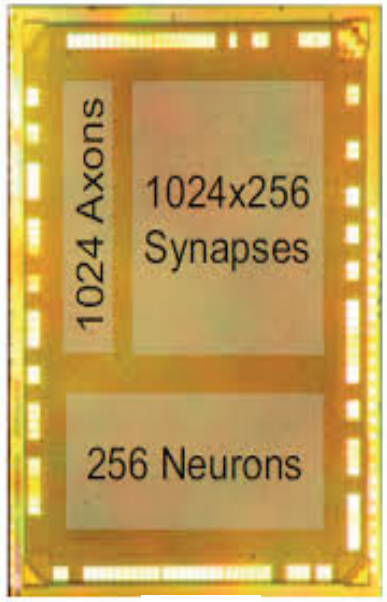
Automated insights pose **unique IC challenges**

Reconfigurable Accelerator for Deep Learning Networks



Vivienne Sze, MIT
Eyeriss ***ISSCC 14.5***

Brain-Inspired Custom Chip

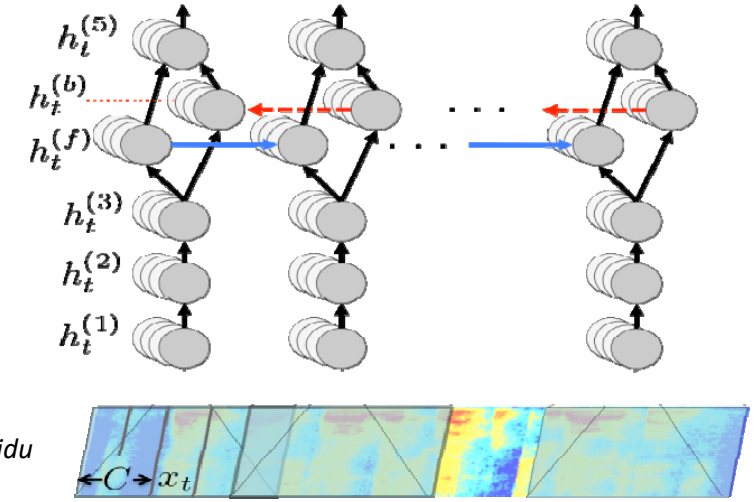


IBM TrueNorth

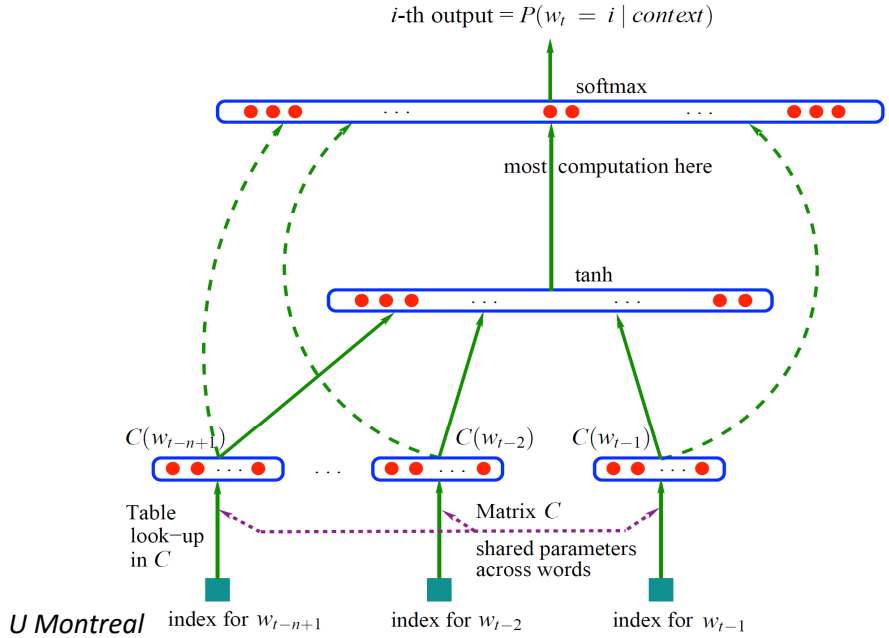
Low-cost deep-learning hardware with embedded **privacy**

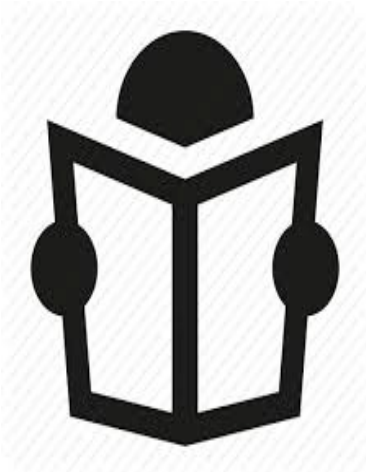
IoE Objects will also learn to **hear**, **read** and **speak**

Audio



Text





… and build **Human Relationships!**

*"The technology will **disappear into the fabric of everyday life**"*

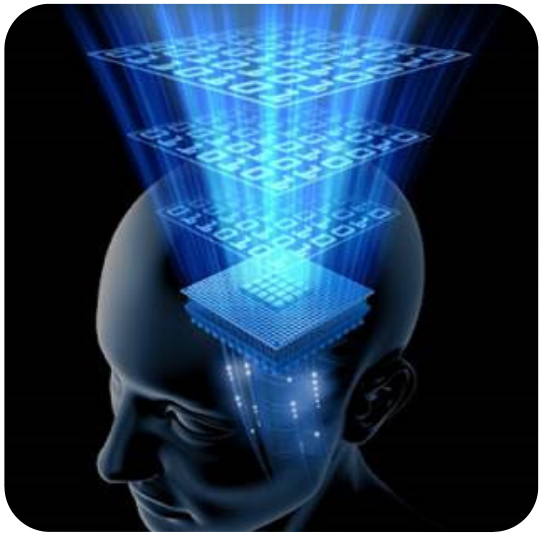
jibo

Cynthia Breazeal

Summary

1. Smart Everyday Objects

2. Information-Centric Networks



3. Automated Real-Time Insights

These pillars pose unique challenges that our **ISSCC community is ideally positioned** to solve

Academics whose research is highlighted

Thank you!

Janos Veres

1. Smart Everyday Objects

Ignacio Solis

2. Information-Centric Networks

Tong Sun

3. Automated Real-Time Insights

parc
A Xerox Company

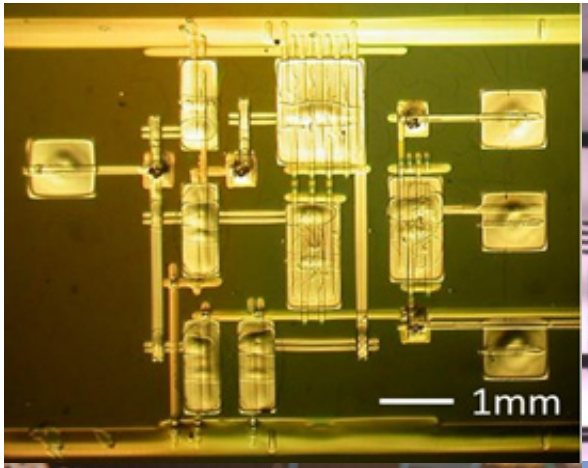
Thank you!

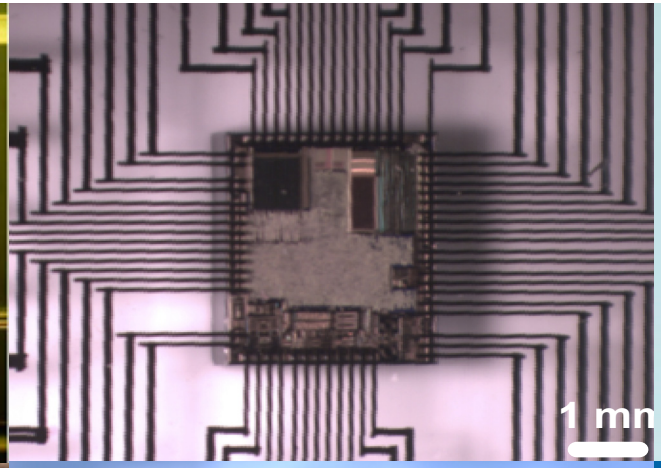
Janos Veres

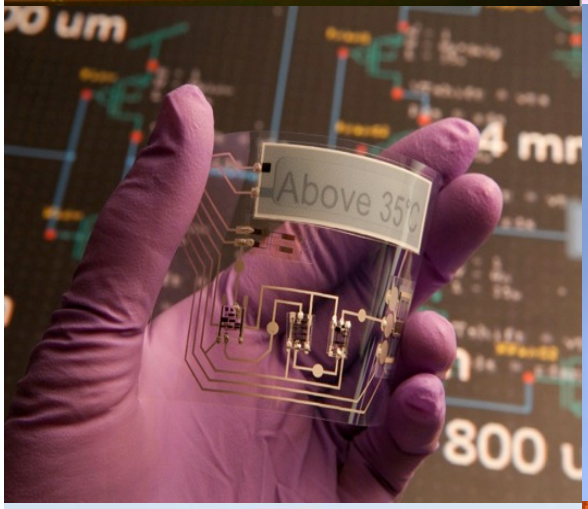
Ignacio Solis

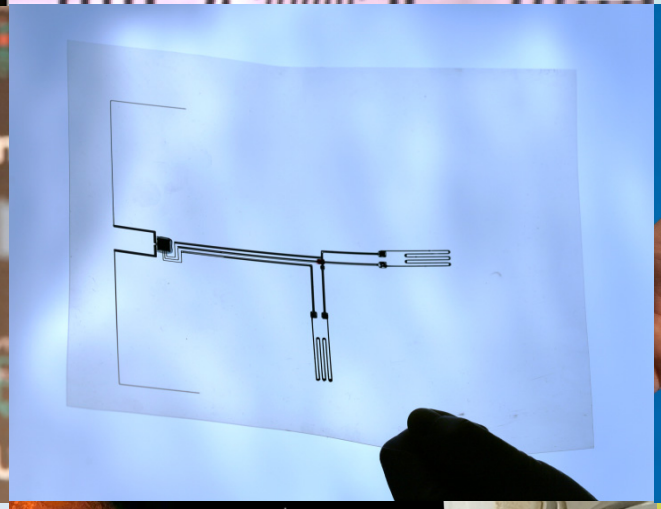
Tong Sun

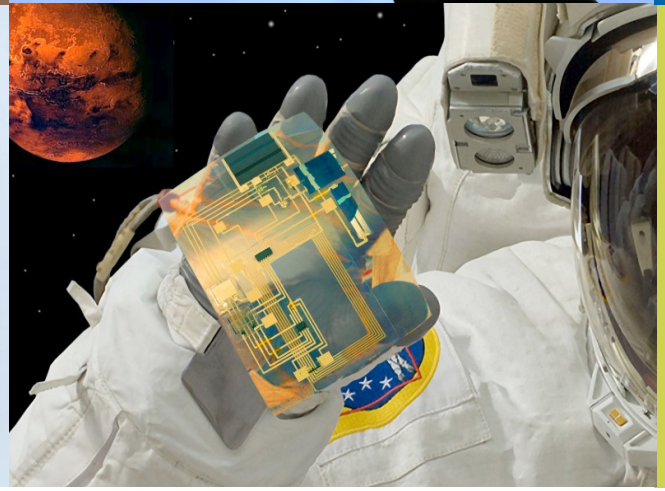
and to the **Xerox researchers** and
our **collaborators** around the globe











Thank you!

Sophie Vandebroek

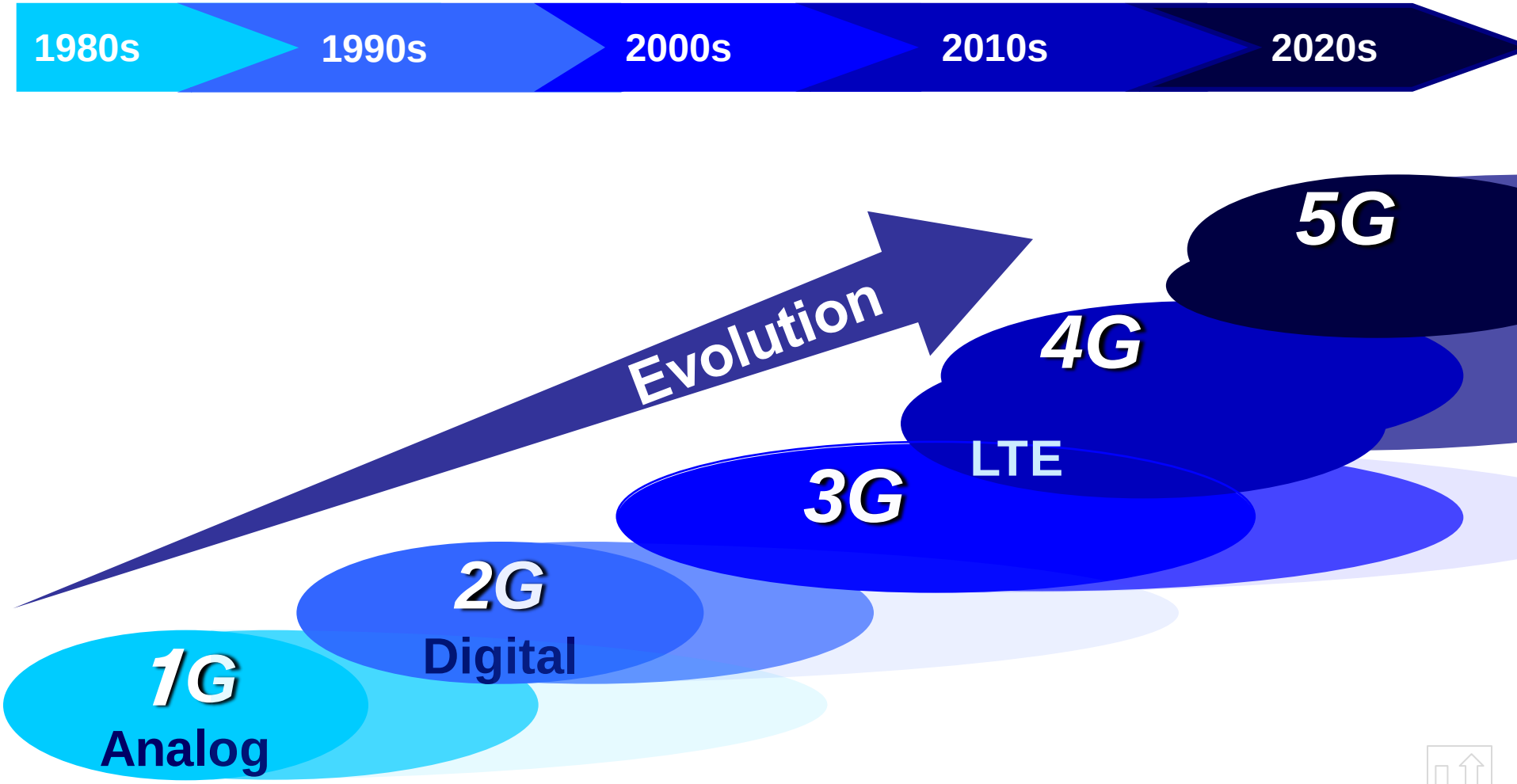
Chief Technology Officer

xerox

The Evolution of 5G Mobile Technology Toward 2020 and Beyond

Seizo ONOE
CTO and EVP
NTT DOCOMO, INC.

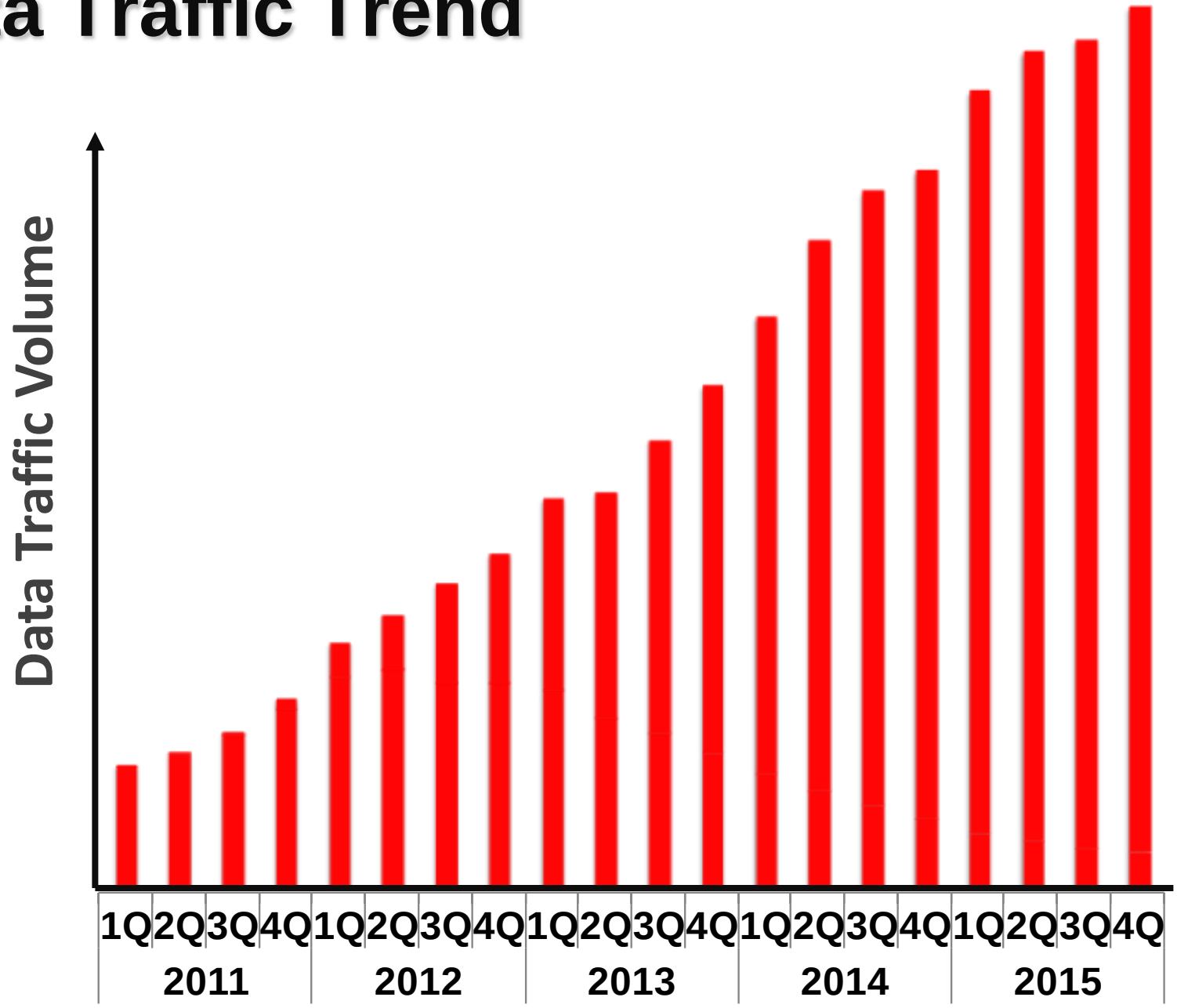
Evolution of Mobile Technology



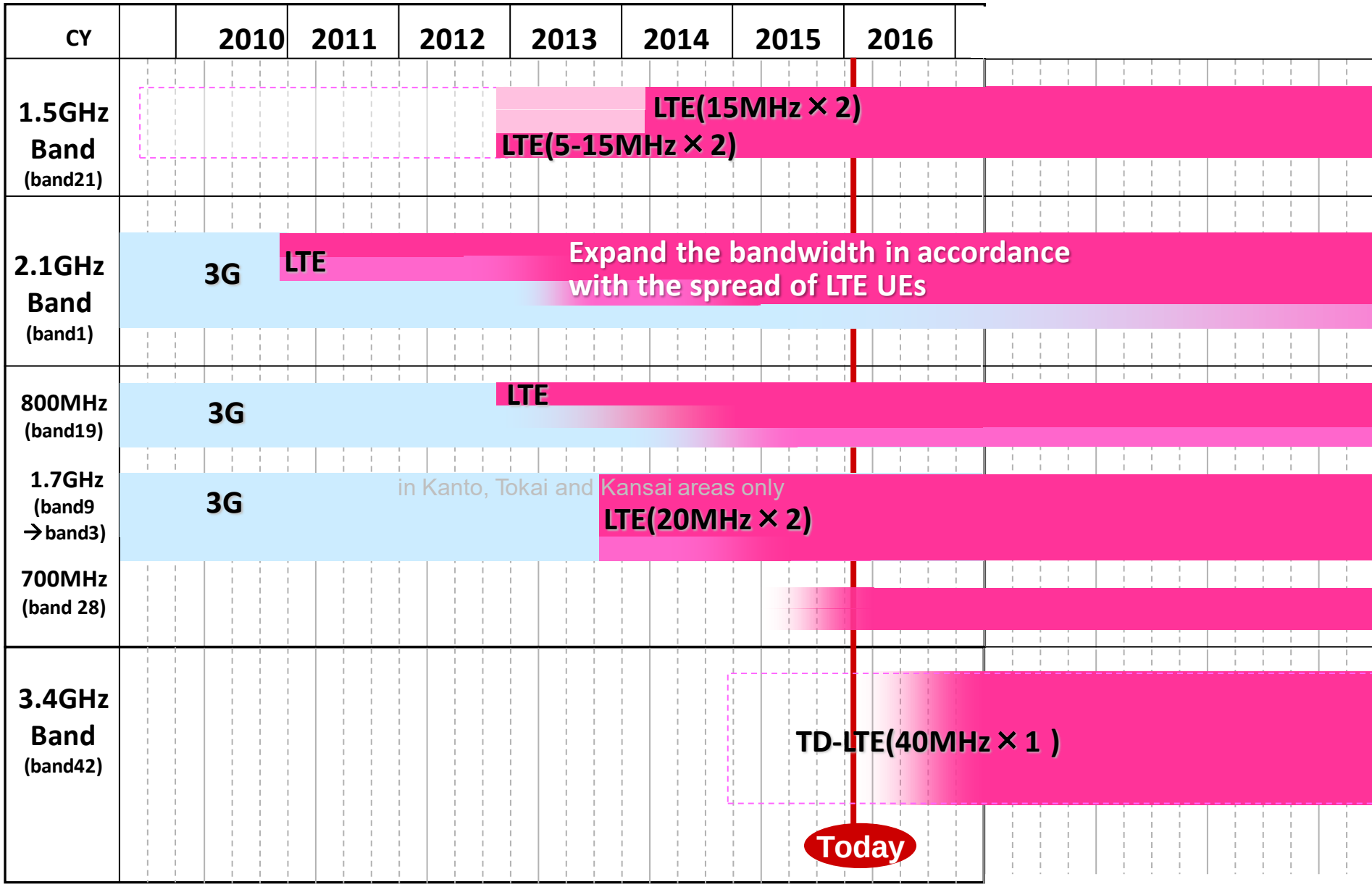
- LTE update
- History and Future
- 5G Discussions
- 5G Technology
- Myth about 5G

LTE Update

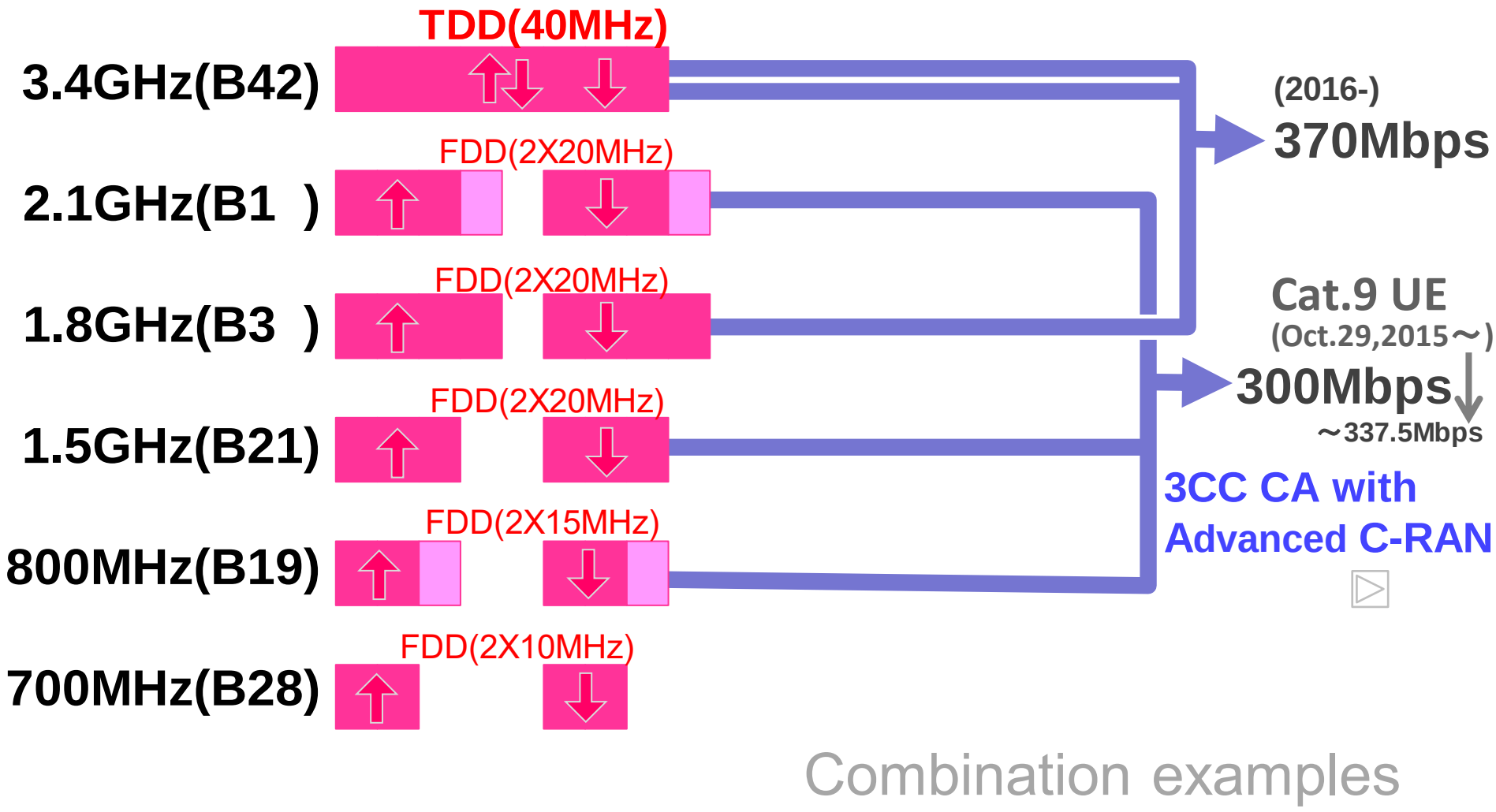
Data Traffic Trend



Frequency Bands (DOCOMO)



DOCOMO's Operating Bands



LTE is successful for DOCOMO and global deployment.

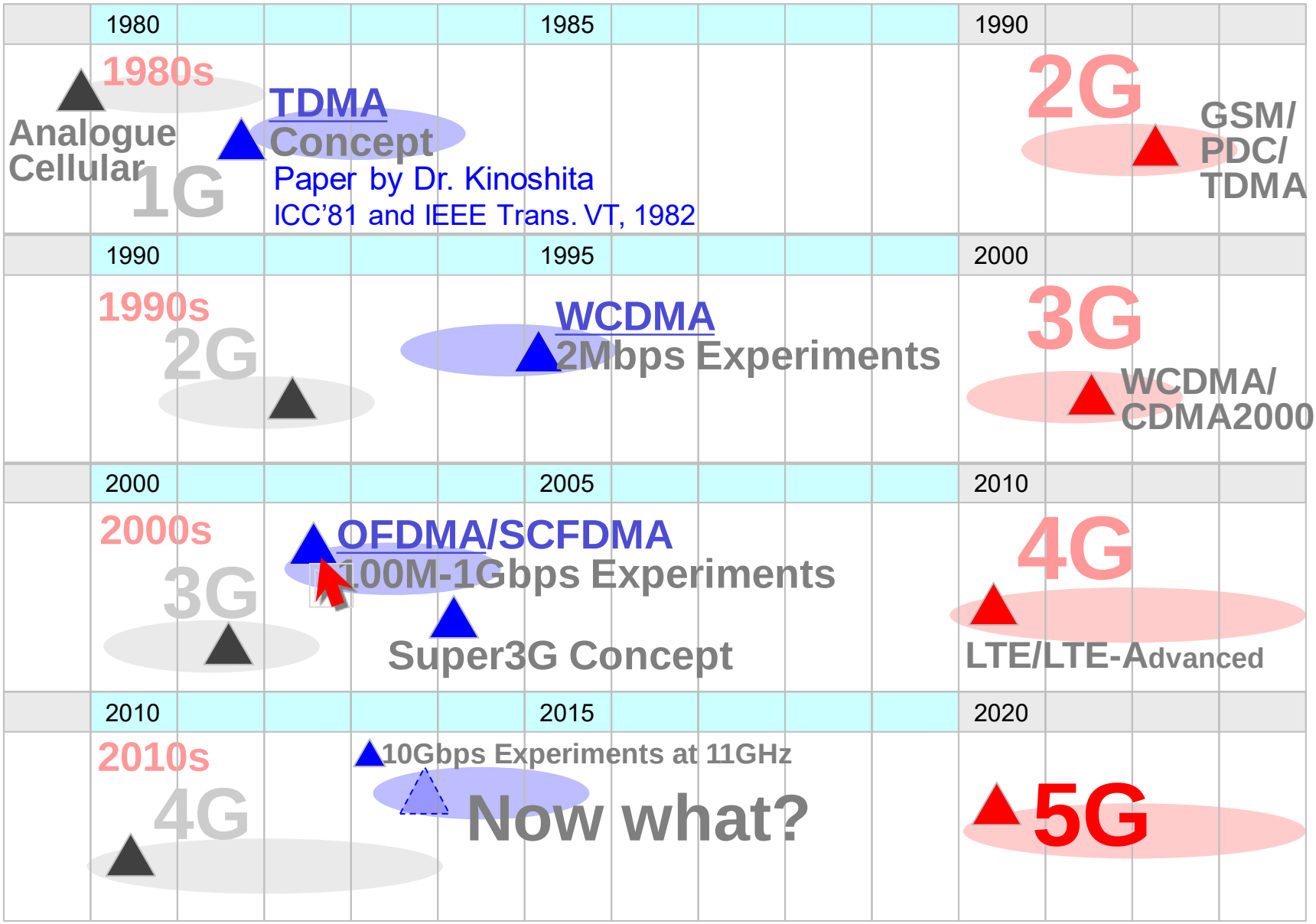
What was behind the success?

- Lessons learnt from 3G launch
  - Lesson 1: Launch timing
  - Lesson 2: Smooth path to the next generation

History and Future

History from 1G to 4G and the Next

Details



History of 4G Research at DOCOMO

Background: 4G research outcome of over 1Gbps data transmission

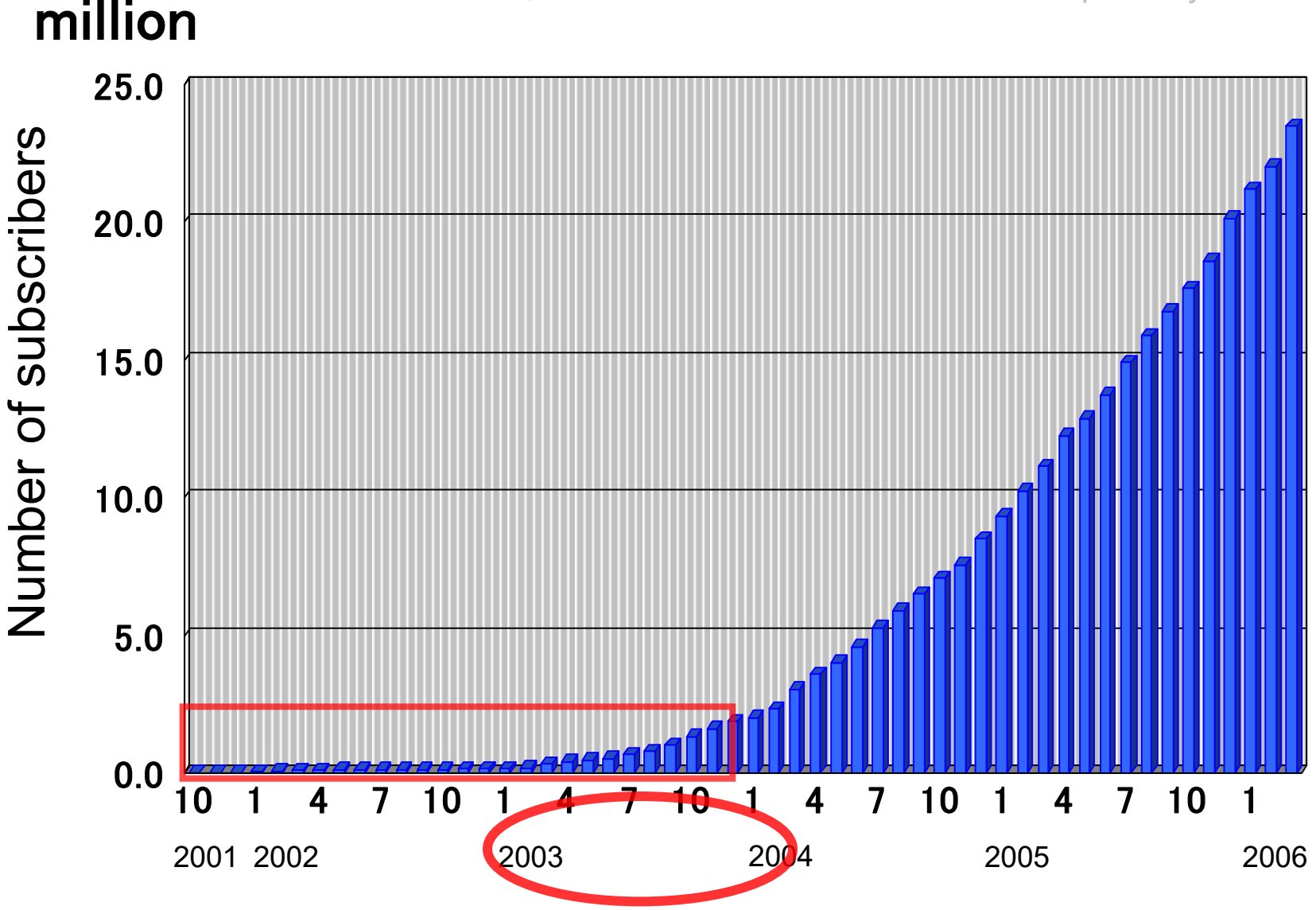
100Mbps
in 2002-2003

5Gbps
in 2006

1Gbps
in 2004-2005

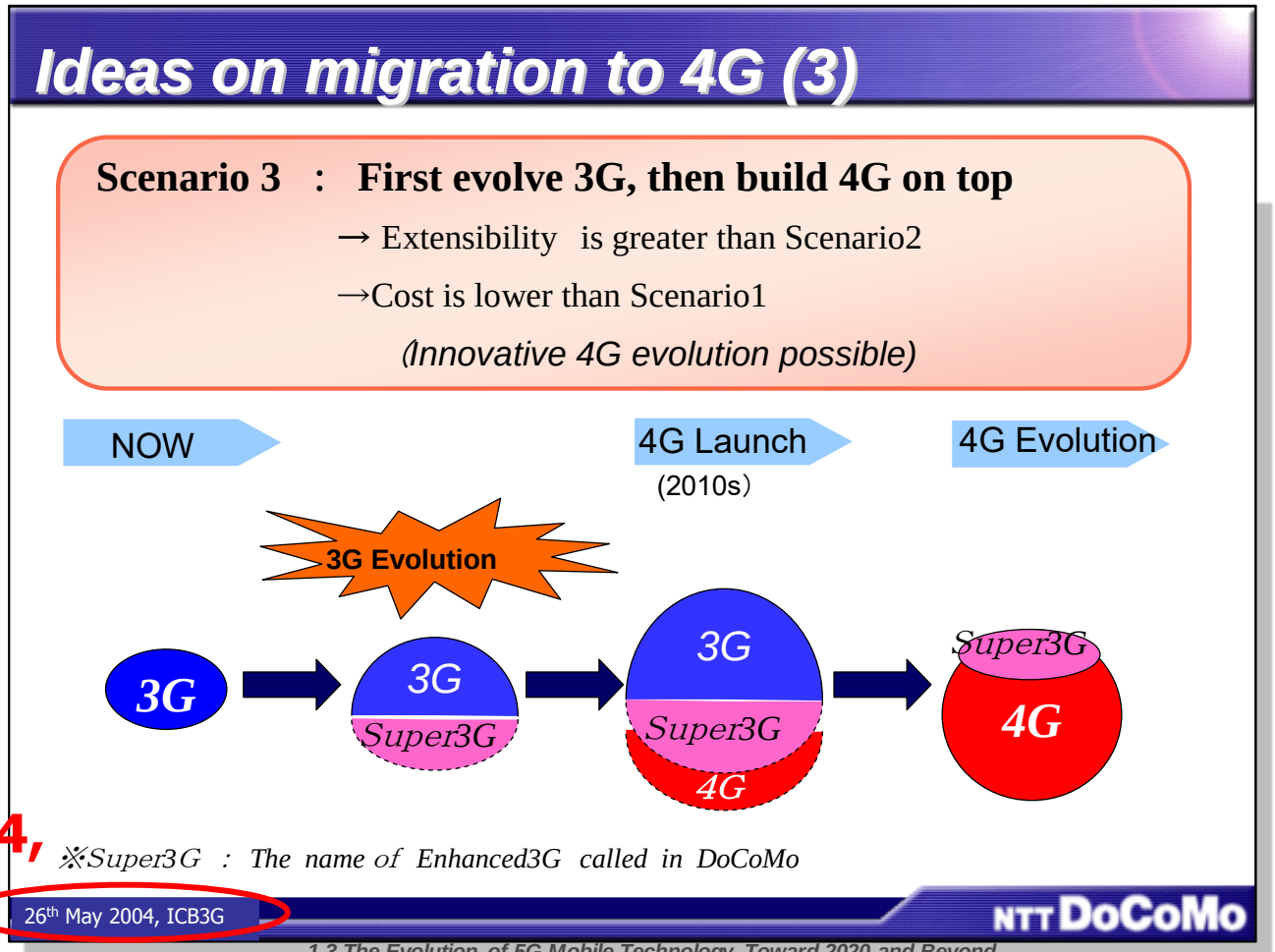
3G Subscriber Growth

On the other hand, 3G services had not been well accepted by the market.



Super3G concept

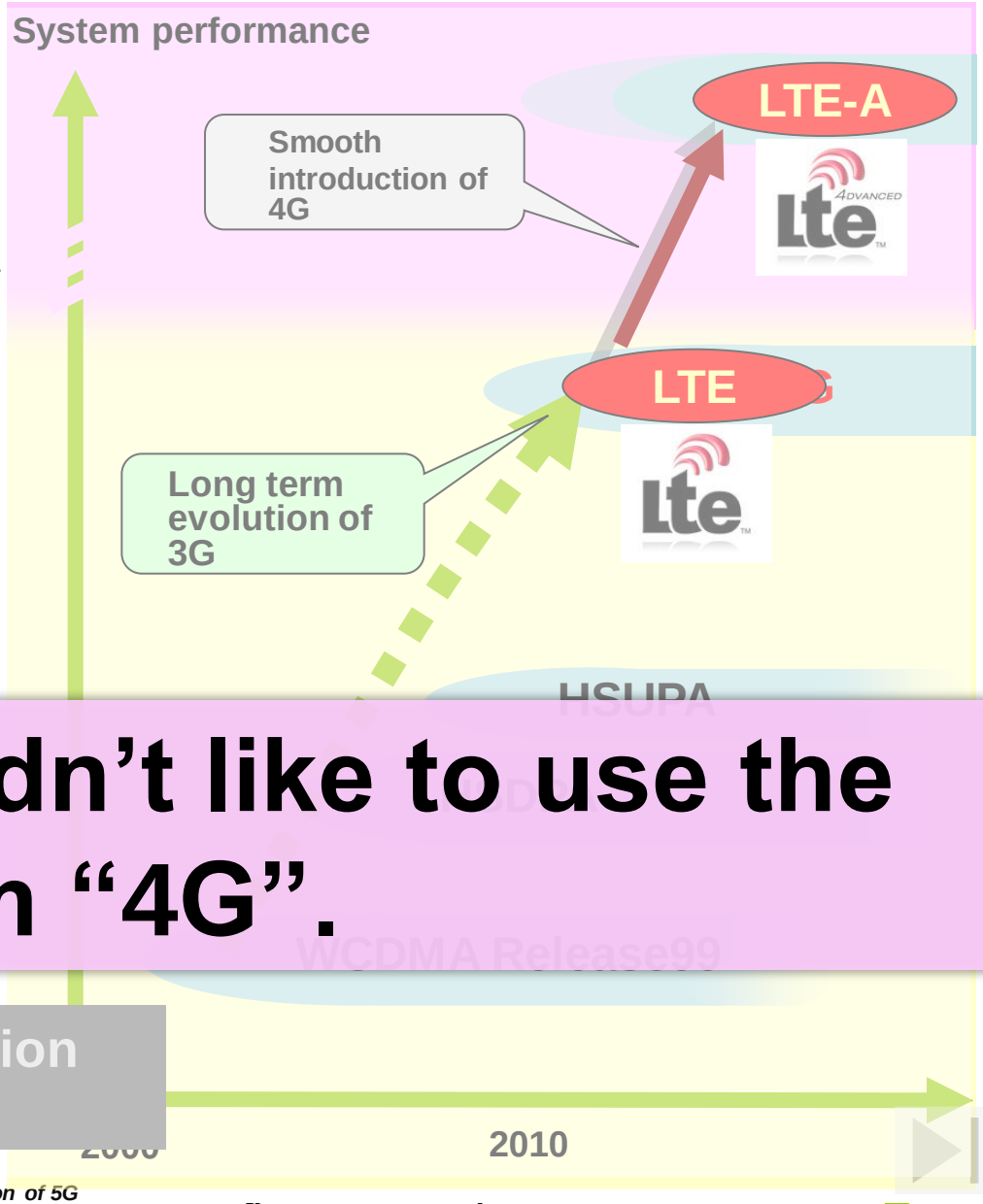
Smooth path to the next generation was essential.
⇒In, 2004, DoCoMo proposed Super3G concept for the smooth path to 4G.



26th May 2004, ICB3G

Original Aims of Super3G

- Basic concept (Original aims)
  - Long term evolution of 3G
    - Evolve 3G technologies by maintaining competitiveness
    - Provide a smooth introduction path to 4G
- Background
  - At the start of standardization in 2004, interest in 4G was low
  - In 2008, for the proposal to [illegible] clearly indicated that LTE Advanced should be an evolution of LTE



Most people didn't like to use the term "4G".

- LTE provides a smooth evolution path to 4G (LTE-Advanced)

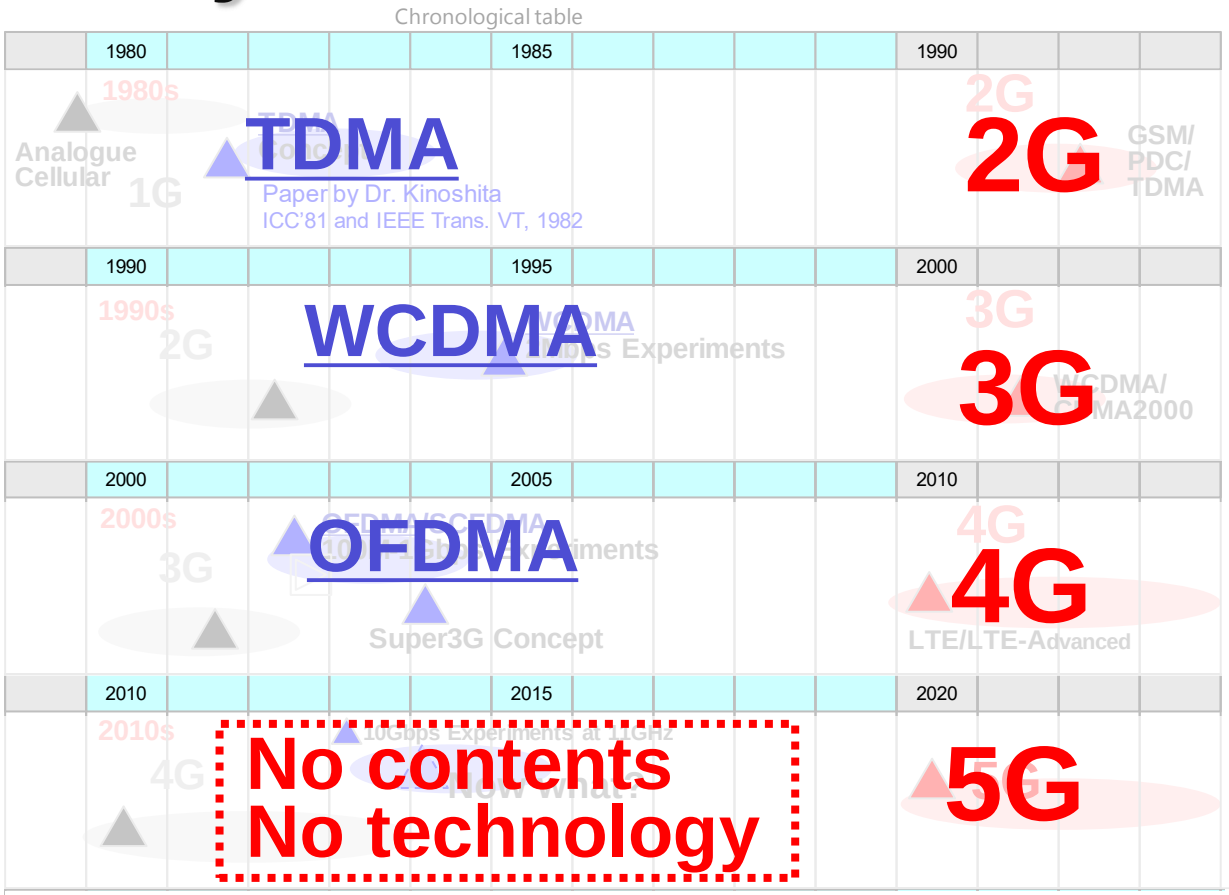
3GPP document contributed by DOCOMO and 25 co-sources

TSG-RAN Meeting #26
RP-040461
Athens, Greece, 8-10, December, 2004
Agenda Item: 8.12
Source: **NTT DoCoMo, Alcatel, Cingular Wireless, CMCC, Ericsson, Fujitsu, Huawei, LG Electronics, Lucent Technologies, Mitsubishi Electric, Motorola, NEC, Nokia, Nortel Networks, Orange, Panasonic, Philips, Qualcomm Europe, Samsung, Sharp, Siemens, Telecom Italia, Telefonica, TeliaSonera, T-Mobile, Vodafone**
Title: **Proposed Study Item on Evolved UTRA and UTRAN**
Document for: **Discussion and approval**

In the RAN Future Evolution Workshop, many of the presentations pointed out the need of 3G long-term evolution to meet the future demand and to maintain its competitive position for coming decades. Several interesting new technology components such as OFDM with a flexible and broader RF bandwidth were presented as potential candidates for the evolution. It was pointed out such a technology enhancement should be applied to UTRAN architecture as well as the UTRA radio interface.
It is proposed that 3GPP should initiate the feasibility study of the long-term evolution accounting for the above situation. In this paper, a Study Item Description is presented for this study.
Concerning the time plan, we propose to complete the feasibility study by June 2006 and envisage all relevant core specifications by June 2007.

History from 1G to 4G and the Next

Details



It's a marketing gimmick after 3G, while technologies were there before 5G

No Tech

No single representative technology, but there are several candidate technologies and the combinations of technologies create new technologies and solutions.

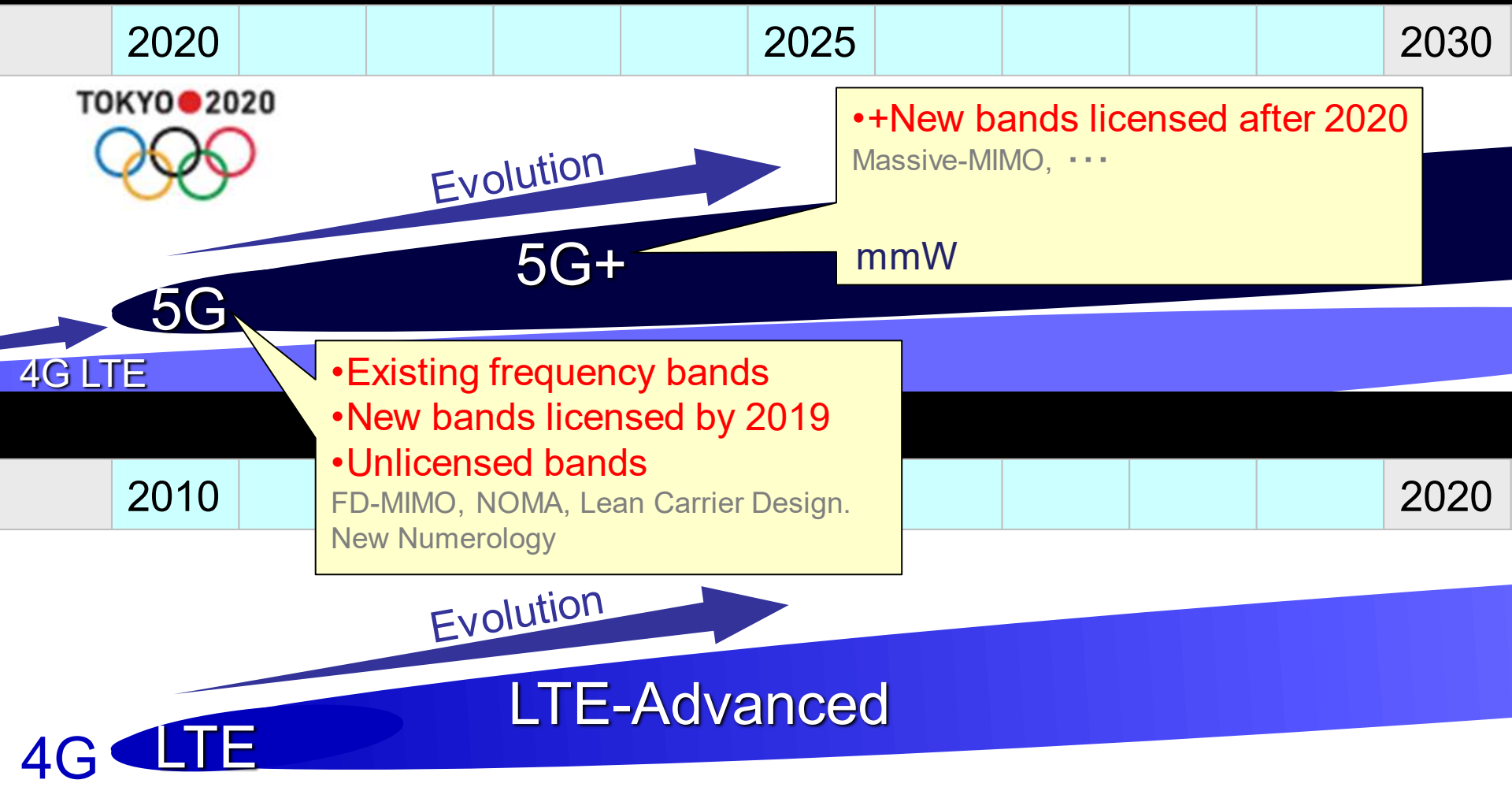
5G Technology

5G Discussions

- Global Activities
- Requirements
- Time Plan
- Concept and Spectrum
- Technology Coverage
- Convergence or Divergence
- Scenarios
- R&D activities

Time Plan

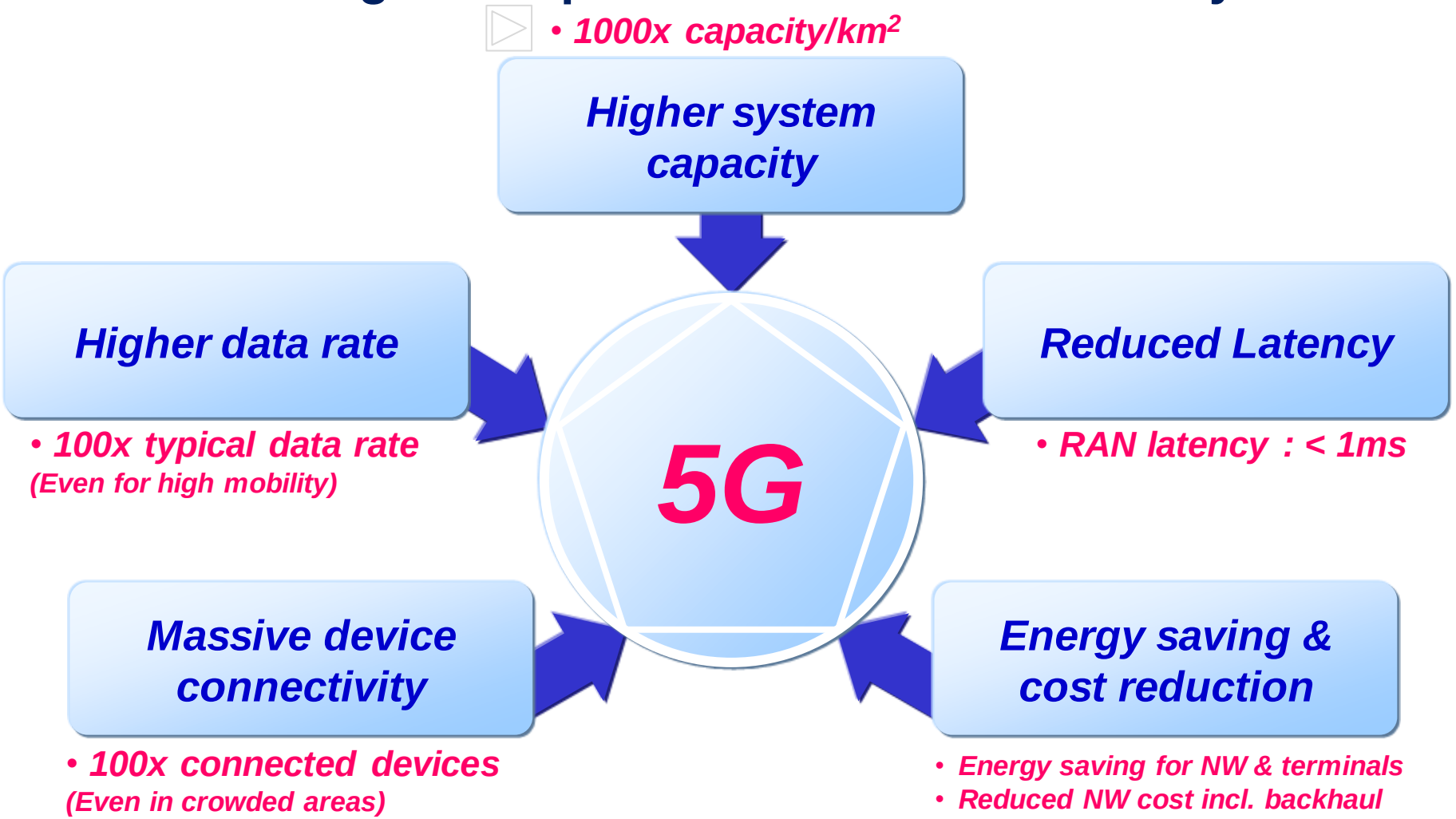
Evolution of Mobile Technology



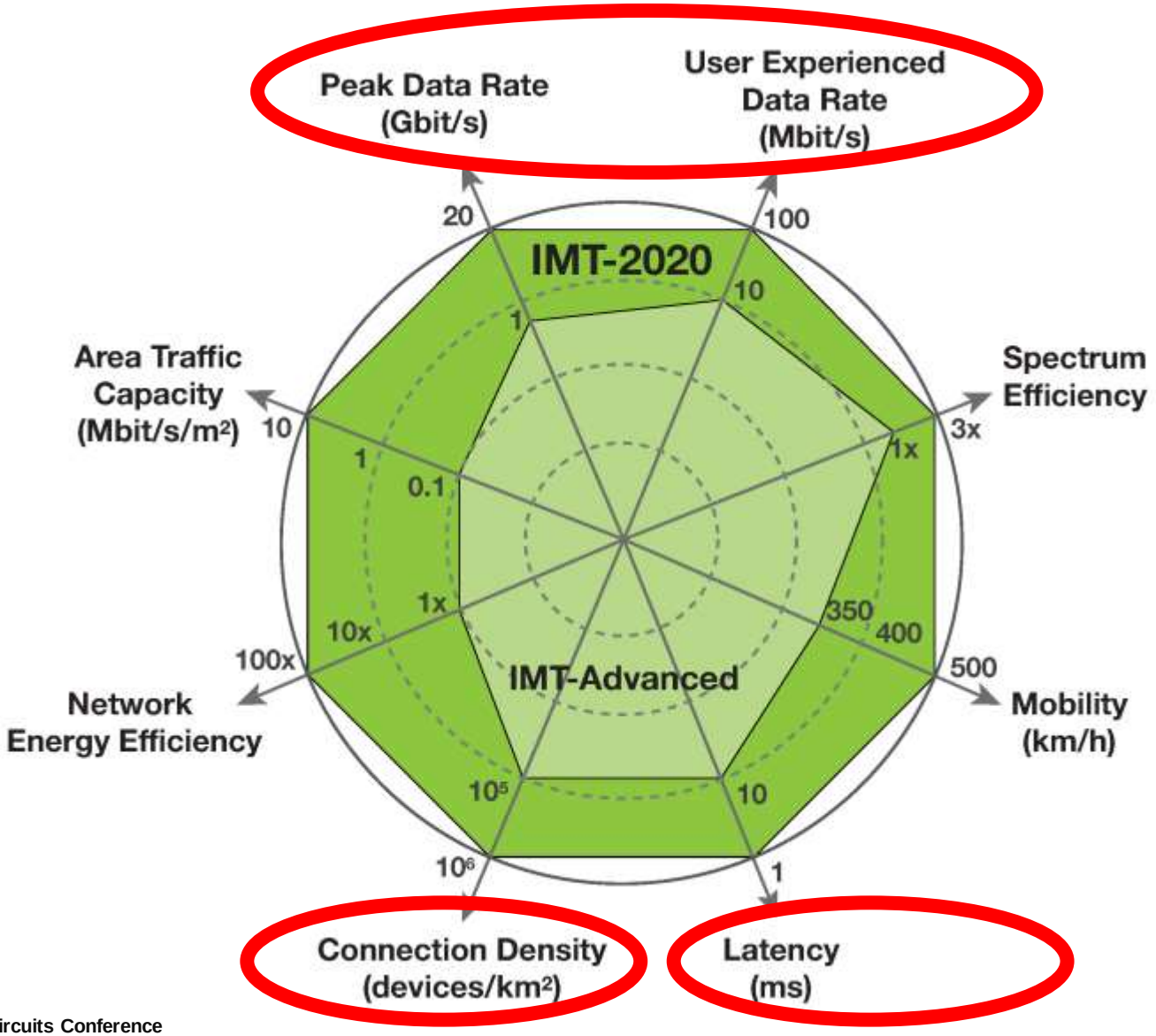
Requirements
What is 5G?

Requirements

5G radio access will provide a total solution to satisfy wider range of requirements for 2020 and beyond



Rec. ITU-R M.2083-0
FIGURE 3
Enhancement of key capabilities from IMT-Advanced to IMT-2020



5G Requirements and Capabilities

- Enhanced Mobile Broadband
- IoT/IoE
  - Massive machine type communications
  - Ultra-reliable and low latency communications
- New Business Models and Ecosystem across Industries

2020

Enhanced Mobile Broadband

5G MBB

High performance

4G LTE/LTE-Advanced

IoT

5G-IoT

NB-IoT

Cat.M

Cat.0

Cat.1

4G LTE

Low power

2020

Enhanced Mobile Broadband

5G MBB

High performance

4G LTE/LTE-Advanced

IoT

5G-IoT

NB-IoT

Cat.M

Cat.0

Cat.1

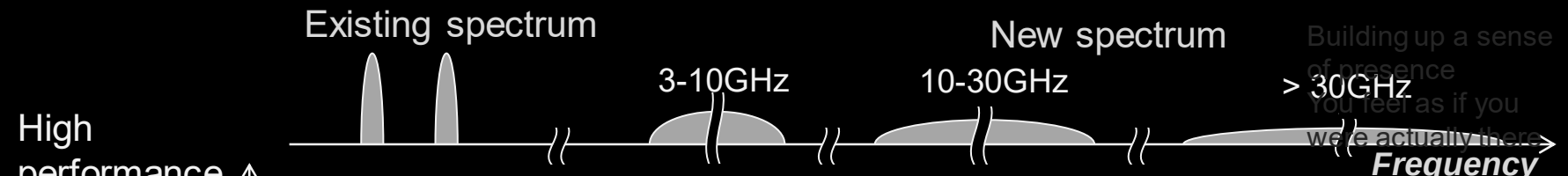
4G LTE

Low power

Technology Coverage for Use Cases and Frequency Bands

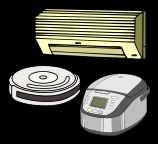
5G utilizes wide range of frequency bands and their combinations with interworks

5G covers wide variety of use cases



High performance

Low-power



Tech. 1

Tech. 2

Tech. 3

Tech. 4

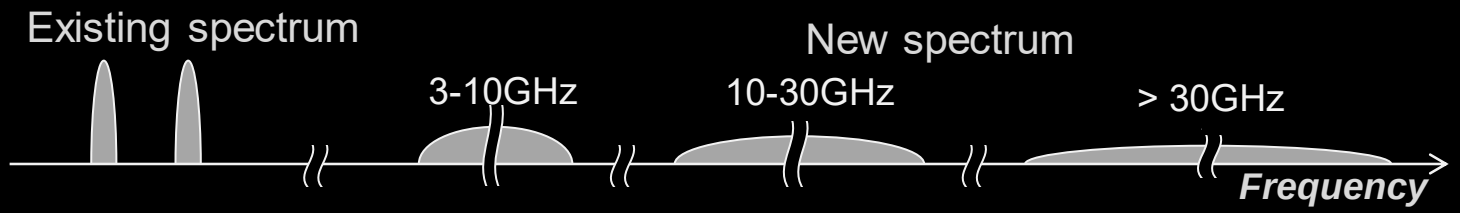
Tech. 5

Tech. 6

Tech. 7

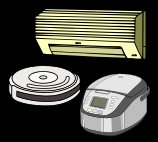
Different technologies may be used for different use cases and different frequency bands.

5G utilizes wide range of frequency bands and their combinations with interworks



5G covers wide variety of use cases

High performance



Low-power

5G

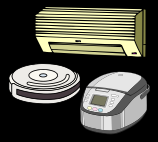
A single technology,
which is consisted of multiple components
with consistent design basis,
is used for whole range.

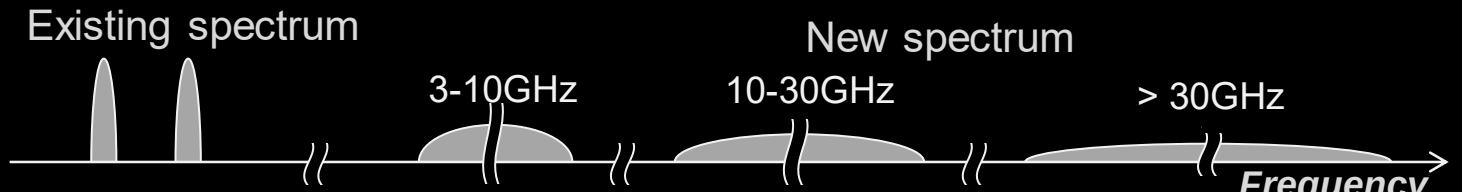
5G utilizes wide range of frequency bands and their combinations with interworks

5G covers wide variety of use cases

High performance

Low-power





5G

A single technology,
which is consisted of multiple components
with consistent design basis,
is used for whole range.

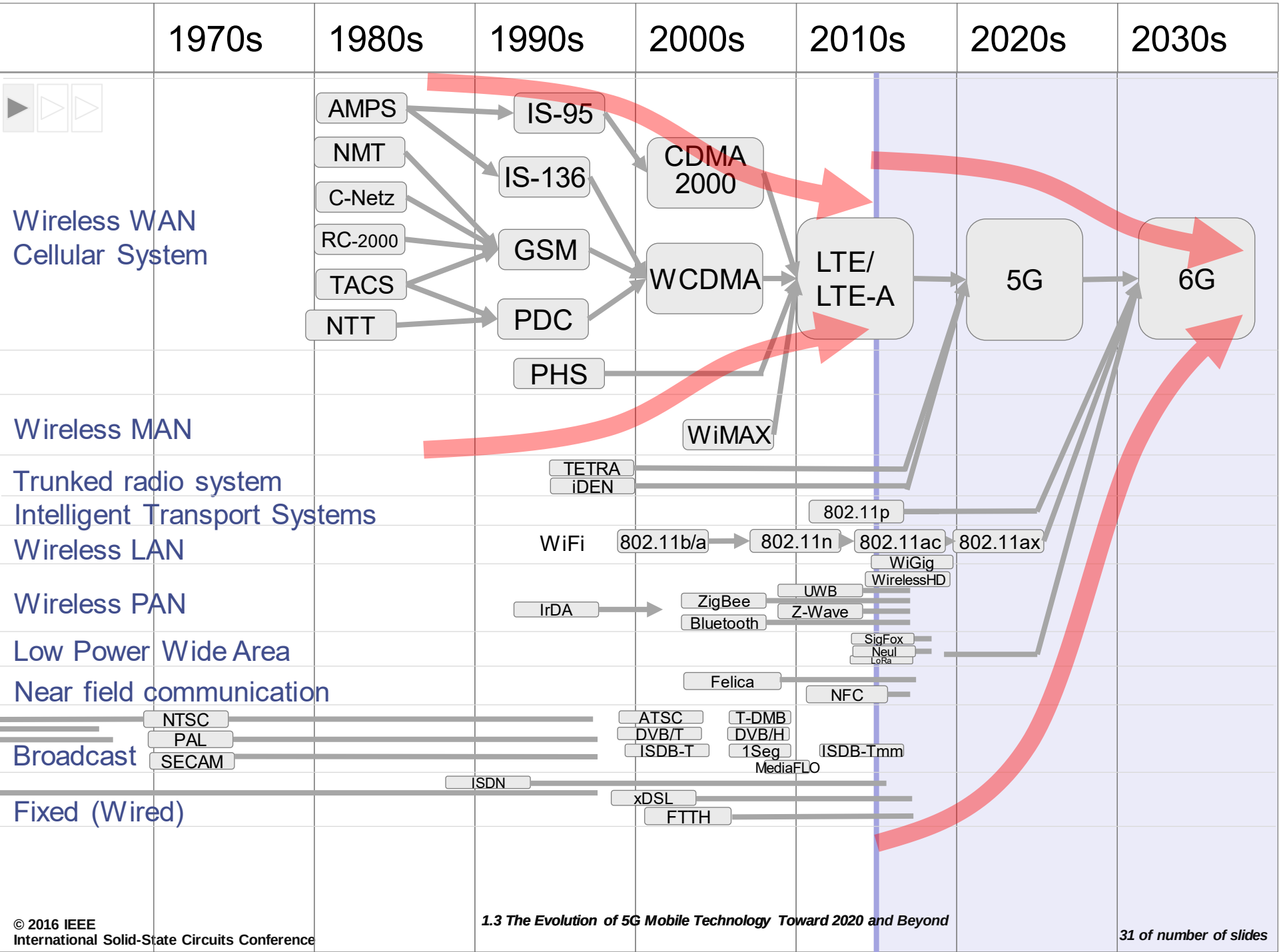
Tech. 4

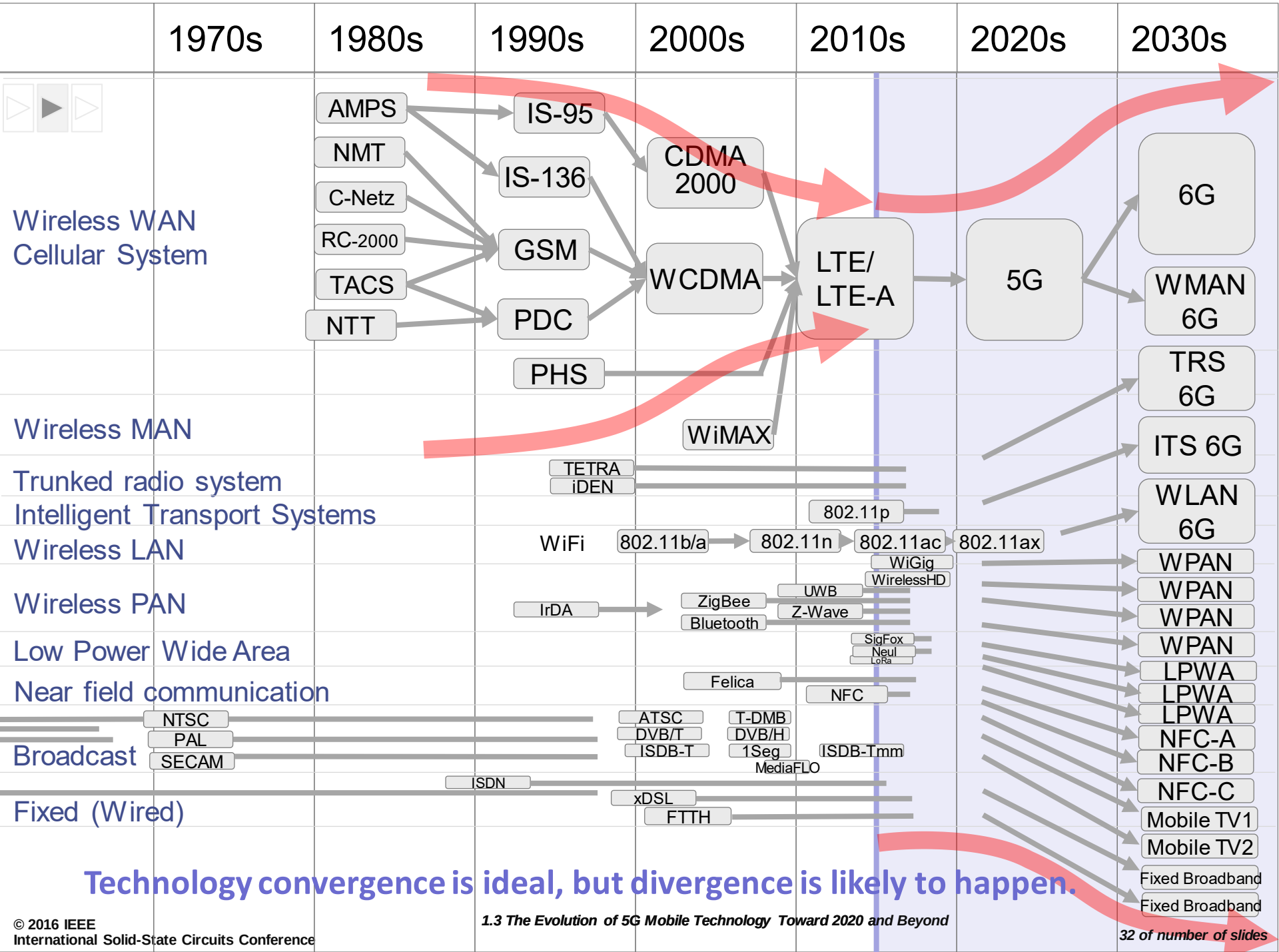
Tech. 7

A major technology and complementary technologies are used.

Tech. 3

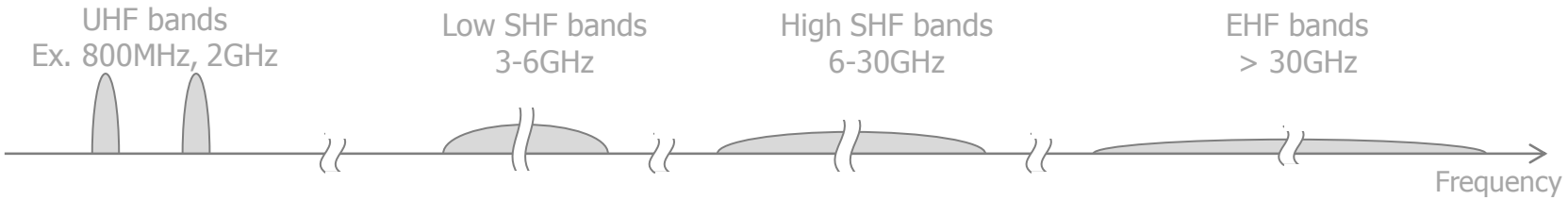
Technology Convergence or Divergence





5G R&D Activities

5G Experimental Trials in DOCOMO with World-leading Vendors



ERICSSON × NTT docomo

Wideband MIMO @ 15GHz band

- 400 MHz Wideband Transmission
- Ultra High Speed Data

NOKIA × NTT docomo

5G Technology

A wrong story I don't like

5G provides Higher data speed and Higher capacity.

➔Broader spectrum bandwidth

➔Higher frequency spectrum

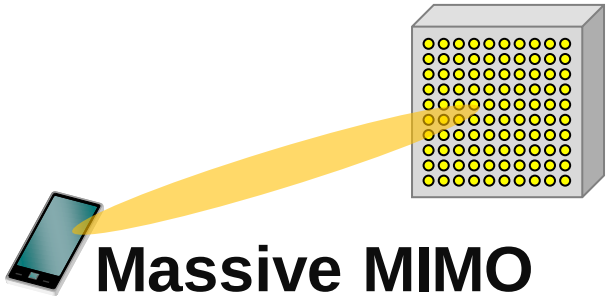
➔Larger propagation loss

➔Shorter coverage

➔5G is a ~~Hotspot system for complementary use.~~

Let's tackle the challenge of achieving wide coverage as cellular systems even with higher spectrum.

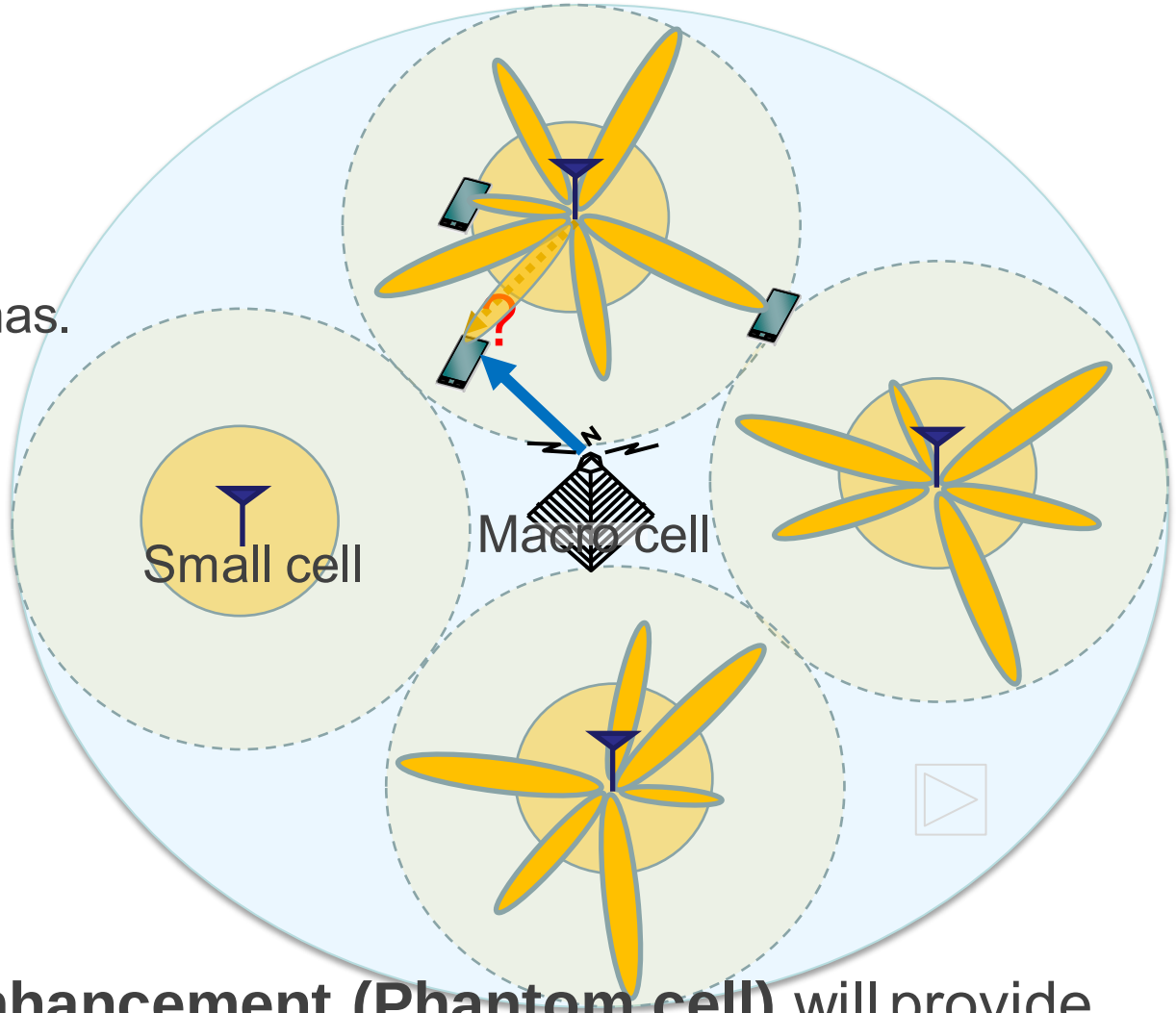
Massive-MIMO and Advanced C-RAN (Phantom cell)



Massive MIMO

is about increasing the number of antennas.

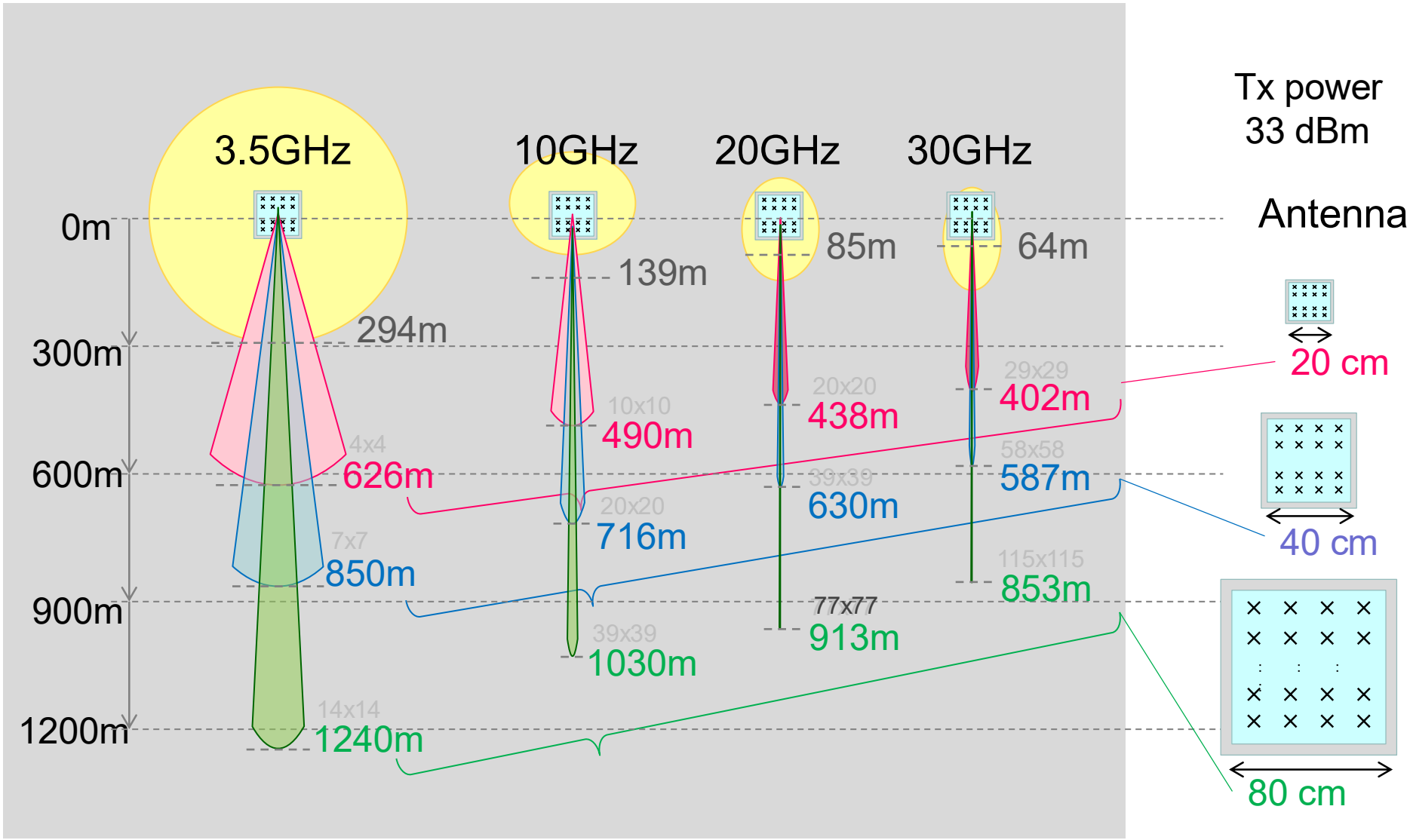
蛮力
~~力業~~ **"Brute force"**



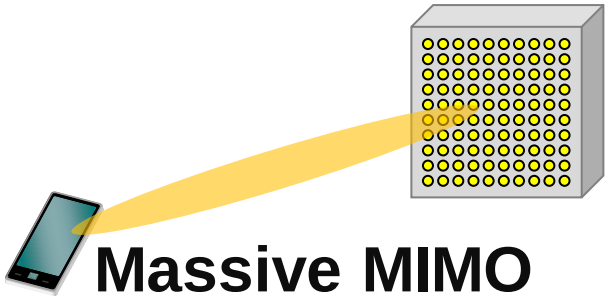
"an excellent feature"

The combination of **Massive MIMO** and **Advanced C-RAN Enhancement (Phantom cell)** will provide adequate cell coverage even with higher frequency bands.

Massive MIMO: Coverage Extension



Massive-MIMO and Advanced C-RAN (Phantom cell)

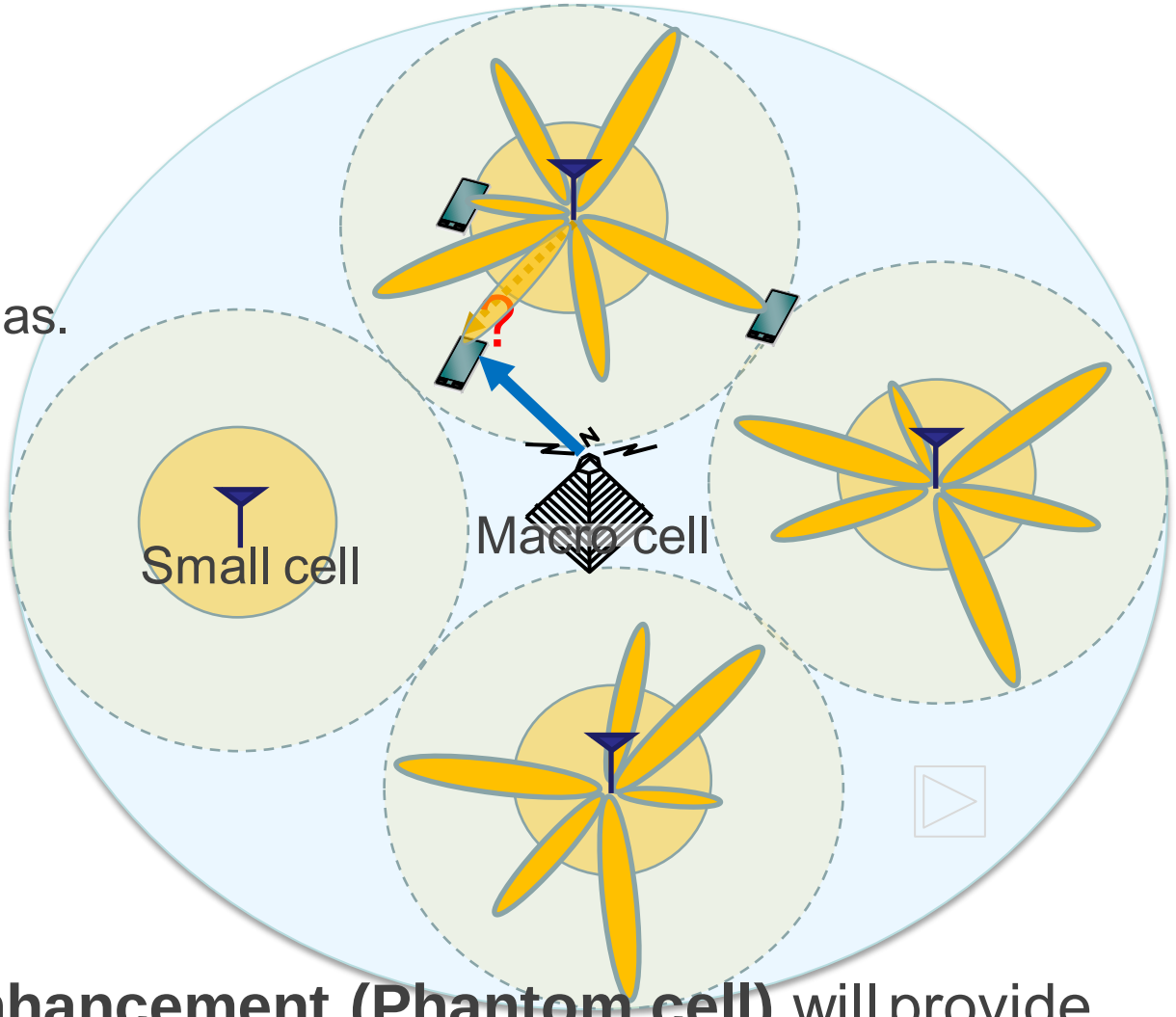


Massive MIMO
is about increasing
the number of antennas.

蛮力
~~力業~~ **"Brute force"**

The implementation technology is key.

"Feat of strength"



"an excellent feature"
The combination of
Massive MIMO and
Advanced C-RAN Enhancement (Phantom cell) will provide adequate cell coverage even with higher frequency bands.

Massive-MIMO and Advanced C-RAN (Phantom cell)

Challenges of Solid-State Circuits in meeting 5G requirements

- RF devices for wide range for frequency bands and bandwidths (0 to100GHz)
- High density implementation of RF and power devices
- High processing power
- Low power consumption

The combination of **Massive MIMO** and **Advanced C-RAN Enhancement (Phantom cell)** will provide adequate cell coverage even with higher frequency bands.

We achieved many things we had thought impossible.

Solid-state devices contributed a lot.

35 years ago

Today

Future

Things we think impossible

7kg

80g

800MHz

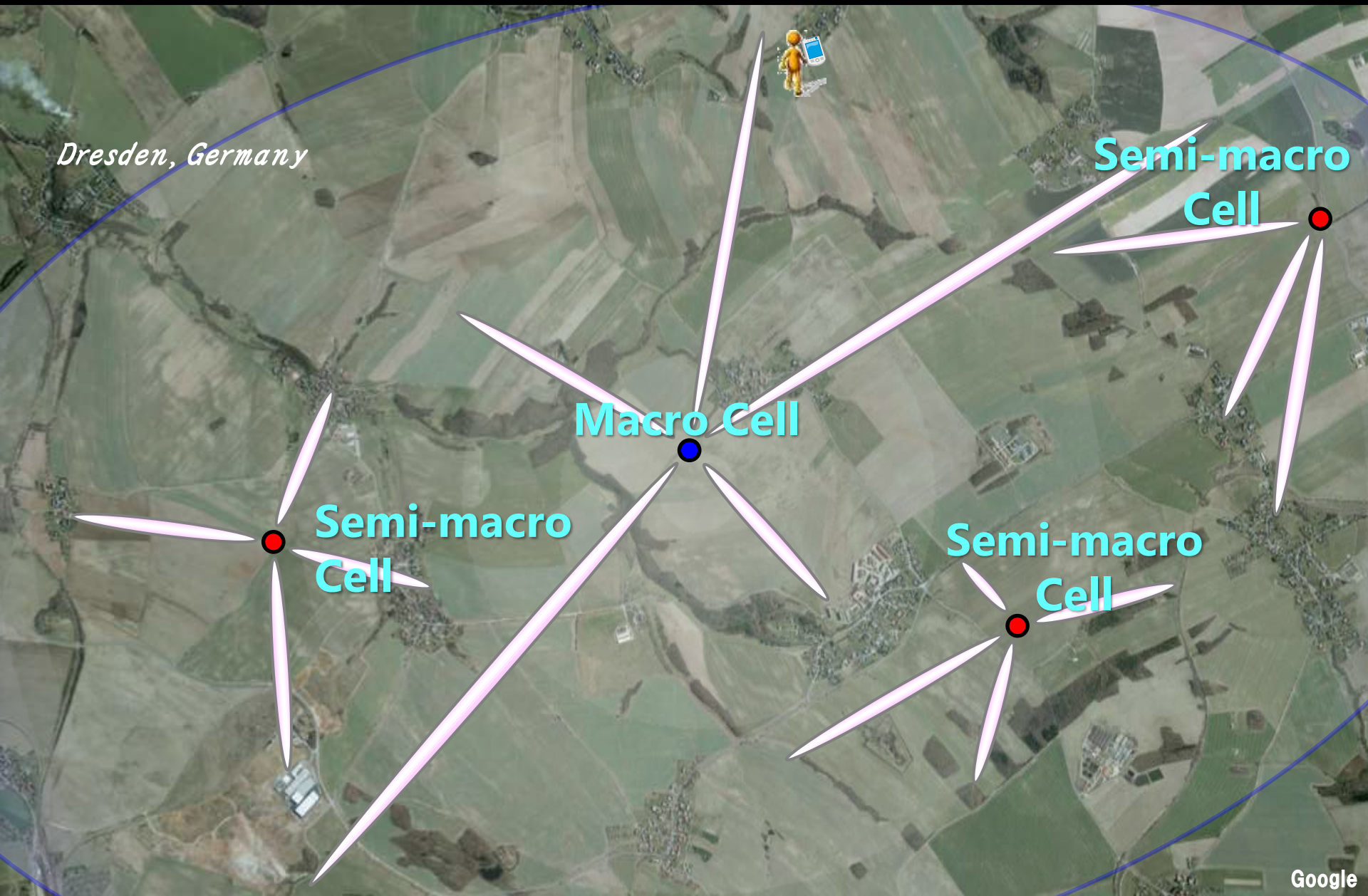
400MHz

2GHz

3.5GHz

100GHz

Massive-MIMO and Advanced C-RAN (Phantom cell)



Myths about 5G

- 5G is millimeter wave technology.
- 5G is a hot spot system.
- 5G needs new 5G spectra.
- 5G is IMT-2020 defined by ITU.
- 5G replaces 4G.
- For 5G, all things need something new.
- 5G needs significant investment.

Conclusion

Conclusion

- 5G is the technology for 2020 and beyond. 5G covers a wide variety of use cases and wide range of frequency bands.
- We expect contributions from solid-state devices for 5G implementation.
- Let's make 5G the technology and capability for 2020 and beyond.

THE ROAD AHEAD FOR SECURELY CONNECTED CARS

Lars Reger
CTO Automotive
NXP Semiconductors

NXP | SECURE CONNECTIONS FOR A SMARTER WORLD

INTERNET OF EVERYTHING

MORE THAN JUST CONNECTING EVERYTHING…

EVERYTHING
CONNECTED

1B+ additional

consumers online

Connectivity

INTERNET OF EVERYTHING

SECURE CONNECTIONS FOR A SMARTER WORLD!

EVERYTHING SECURE

Potential savings

half trillion dollars

Security

EVERYTHING CONNECTED

1B+ additional

consumers online

Connectivity

EVERYTHING SMART

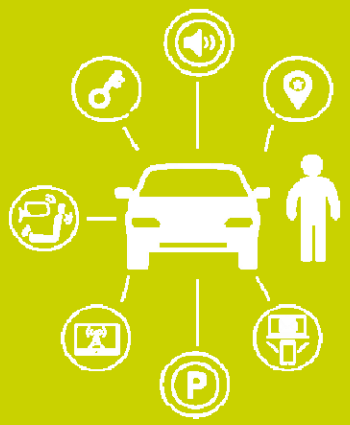
40B+ intelligent devices

shipped in **2020**

Processing

AUTOMOTIVE INNOVATION TRENDS

Seamless
Consumer Electronics
Experience

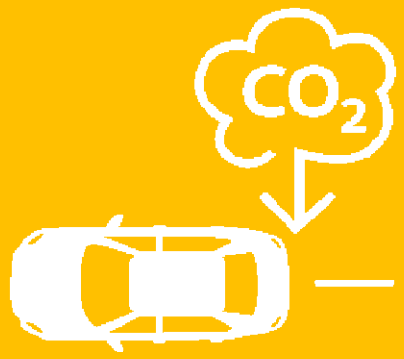


Enjoying Life.
One Hour per Day
in the Car.

Advanced
Driver Assistance
➔ Self-Driving

Saving Lives.
1.3M Fatalities
Every Year.

Energy Efficiency



Reducing CO_2
EU mandates 20%
reduction by 2020.

ROAD TRAFFIC ACCIDENTS

THE CAUSES

Critical Reasons	Number	%
Driver	2,046,000	94%
Vehicles	44,000	2%
Environment	52,000	2%
Unknown	47,000	2%
Total	2,189,000	100%

Data source: NMVCCS

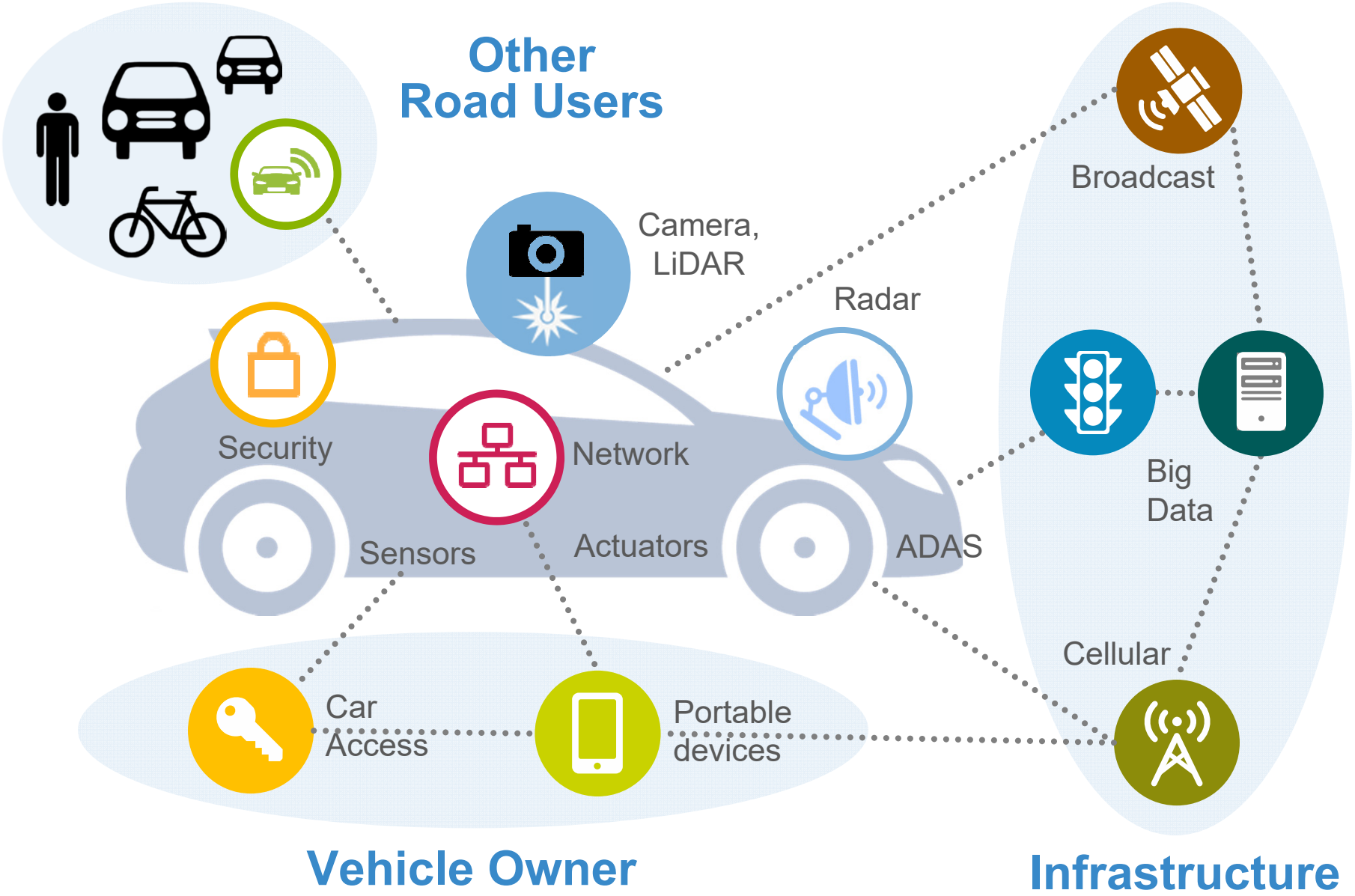
Driver-Related Critical Reasons	Number	%
Recognition Error	845,000	41%
Decision Error	684,000	33%
Performance Error	210,000	11%
Non-performance Error (e.g. Sleep)	145,000	7%
Other	162,000	8%
Total	2,046,000	100%

Every year!

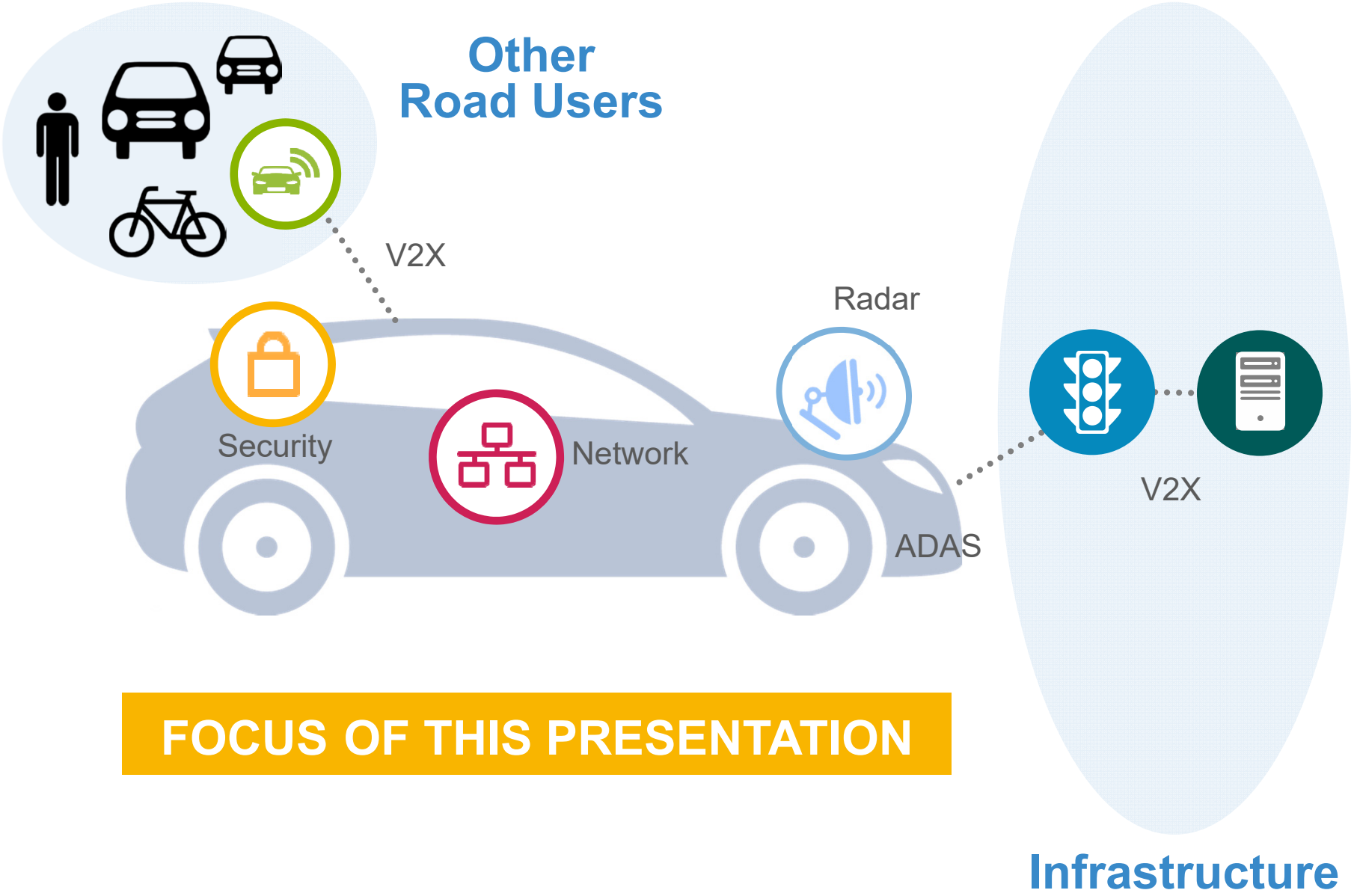
- ~1.3 m fatalities
- >50 m people seriously injured
- >$3 trillion cost of road accidents
- >90% caused by human mistakes

We need to get the *Human Factor* out of the equation!

CONNECTING THE CAR

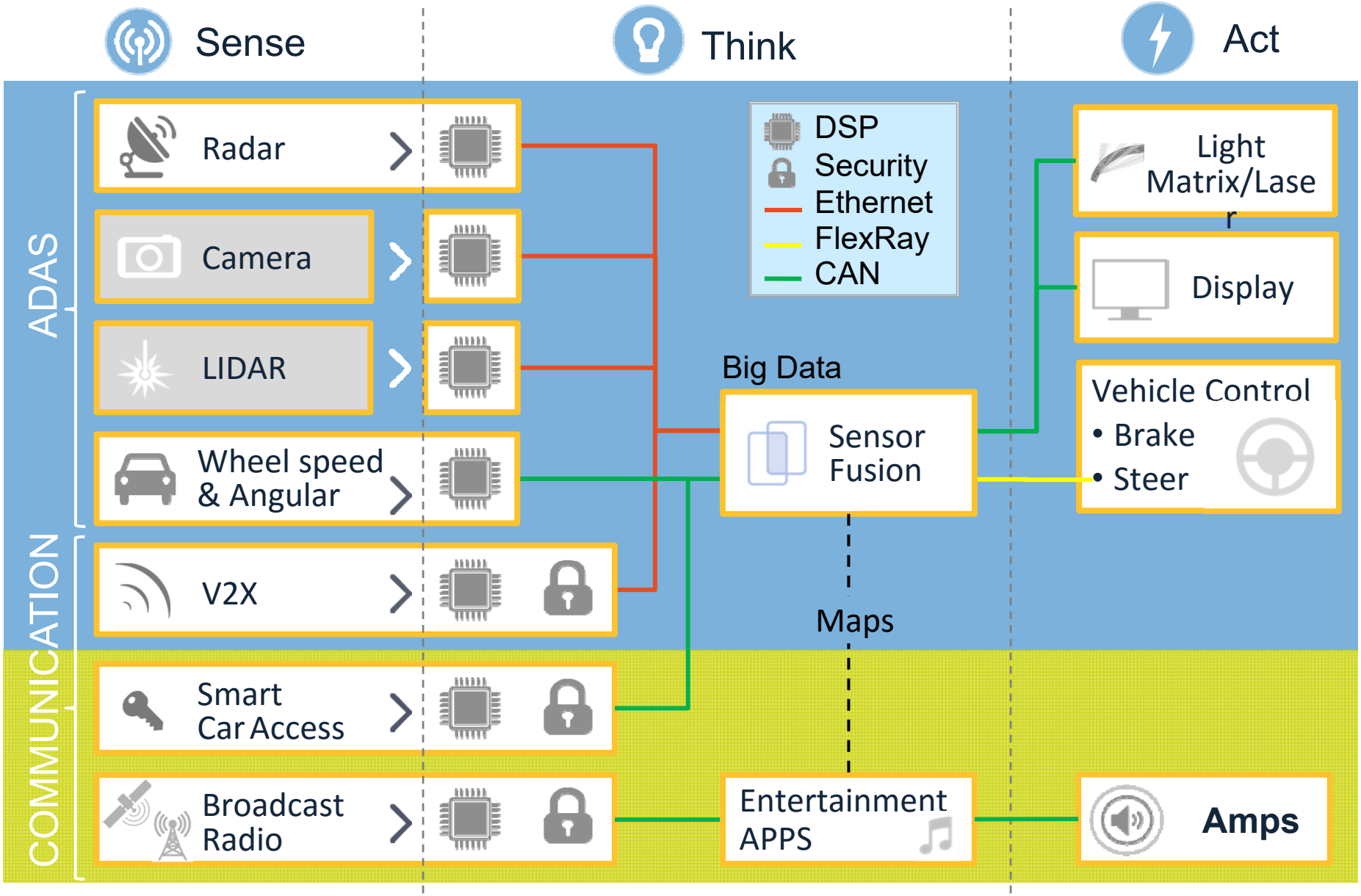


CONNECTING THE CAR

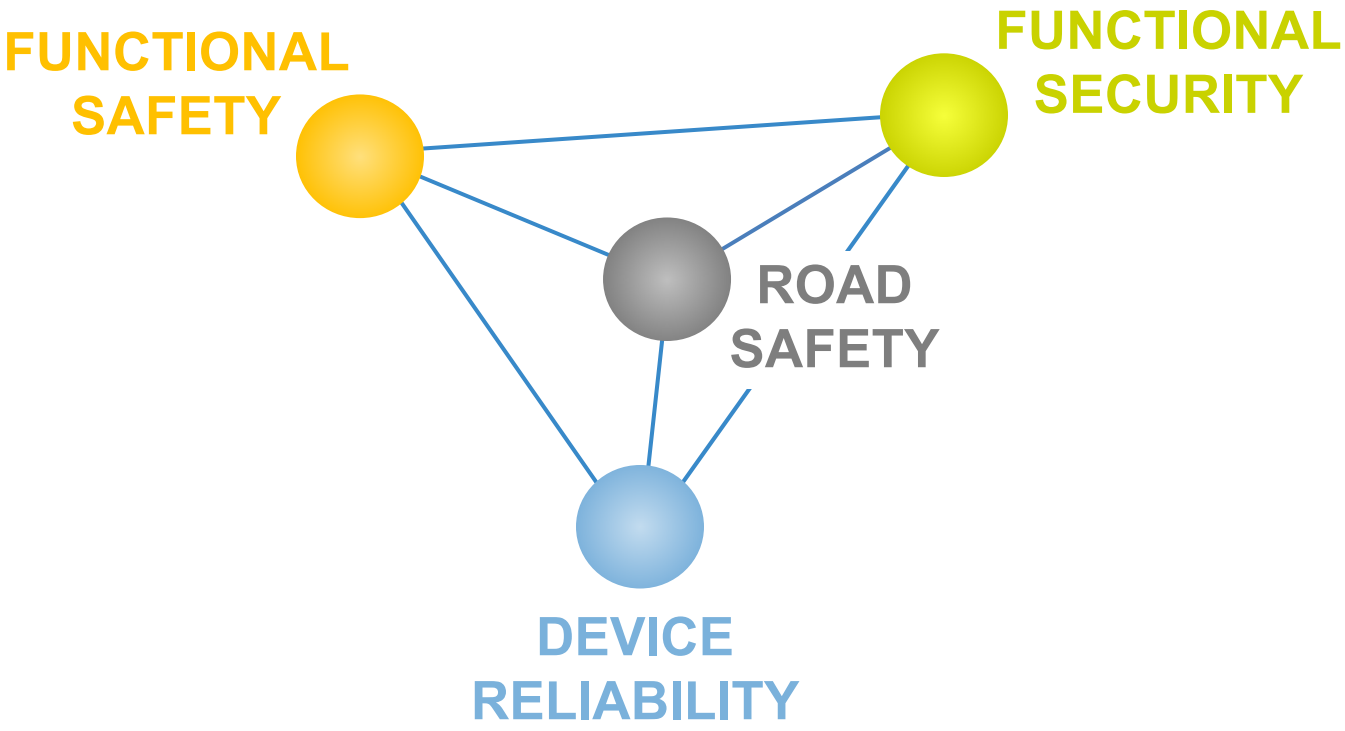


FOCUS OF THIS PRESENTATION

SMART RECEPTION AND SENSING



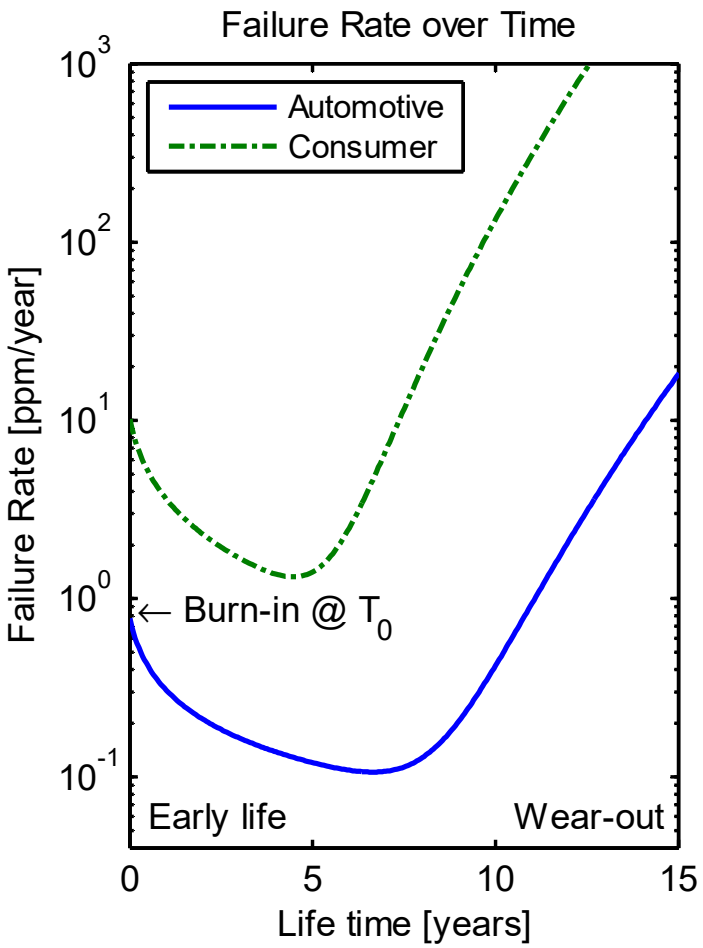
THE ROBUSTNESS TETRAHEDRON

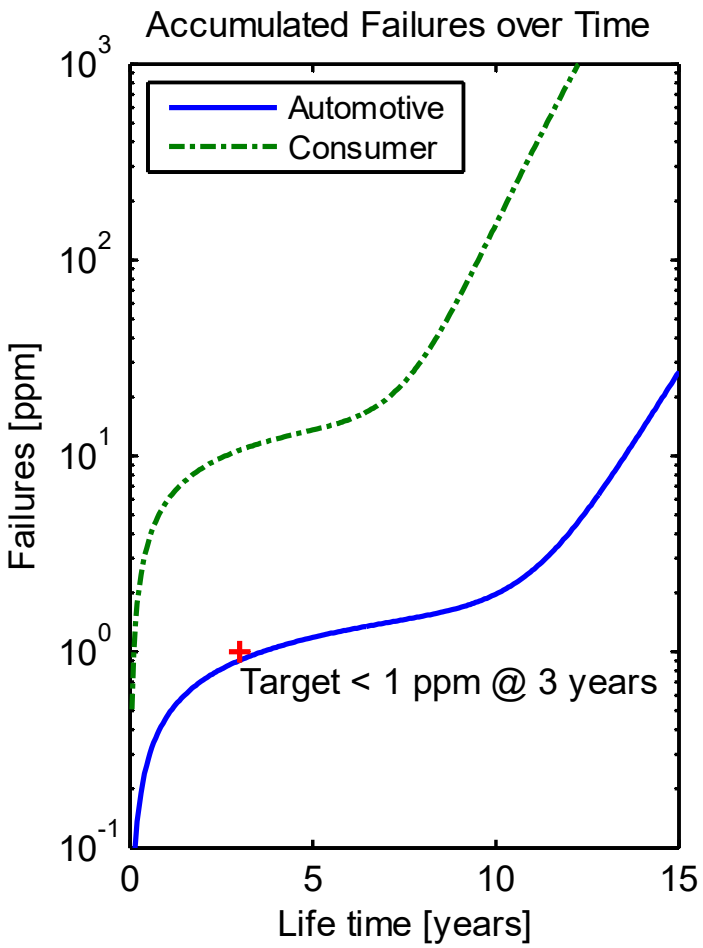


FUNCTIONAL SAFETY:	Zero accidents by system failures (ISO 26262)
FUNCTIONAL SECURITY:	Zero accidents by system hacks
DEVICE RELIABILITY:	Zero components failures (robust design)
ROAD SAFETY:	Zero accidents by human error (ADAS)

RELIABILITY COMPARISON

AUTOMOTIVE VS CONSUMER PRODUCTS

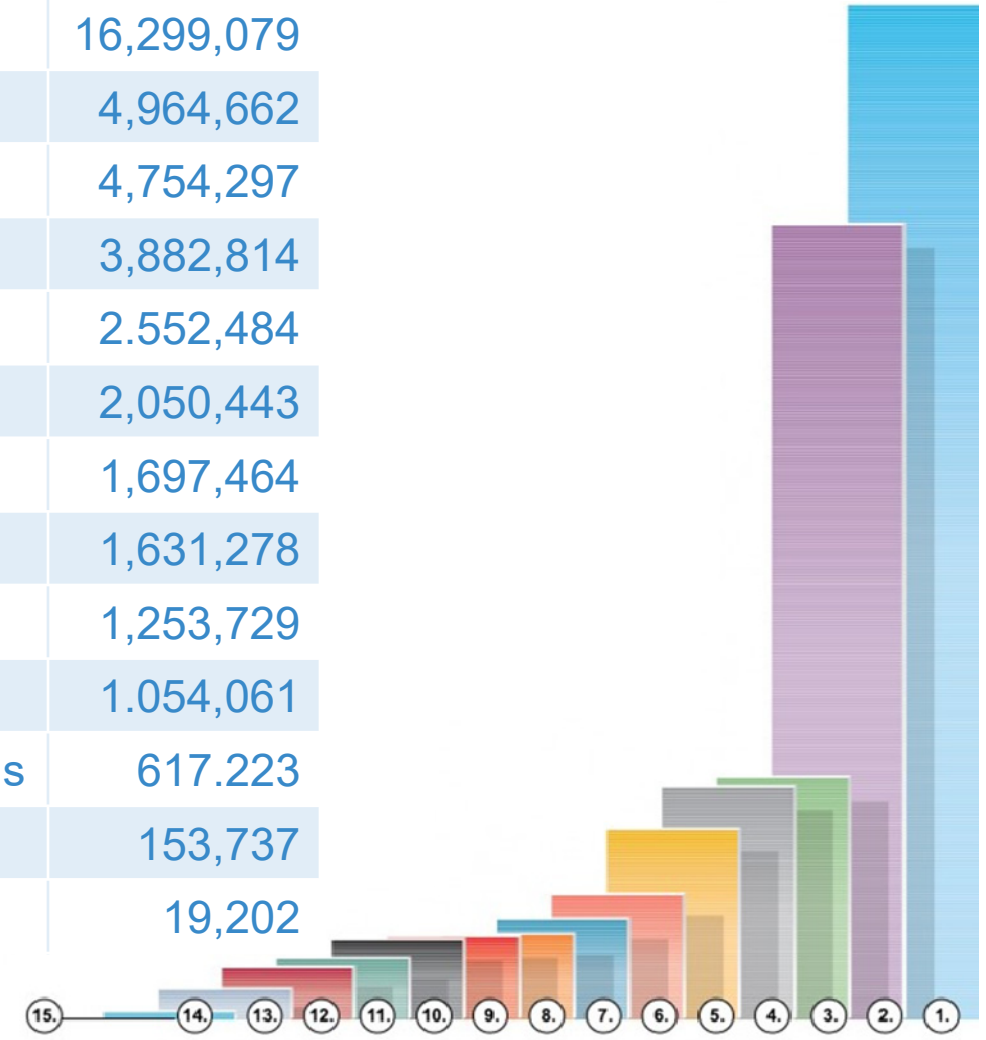




RECALLS

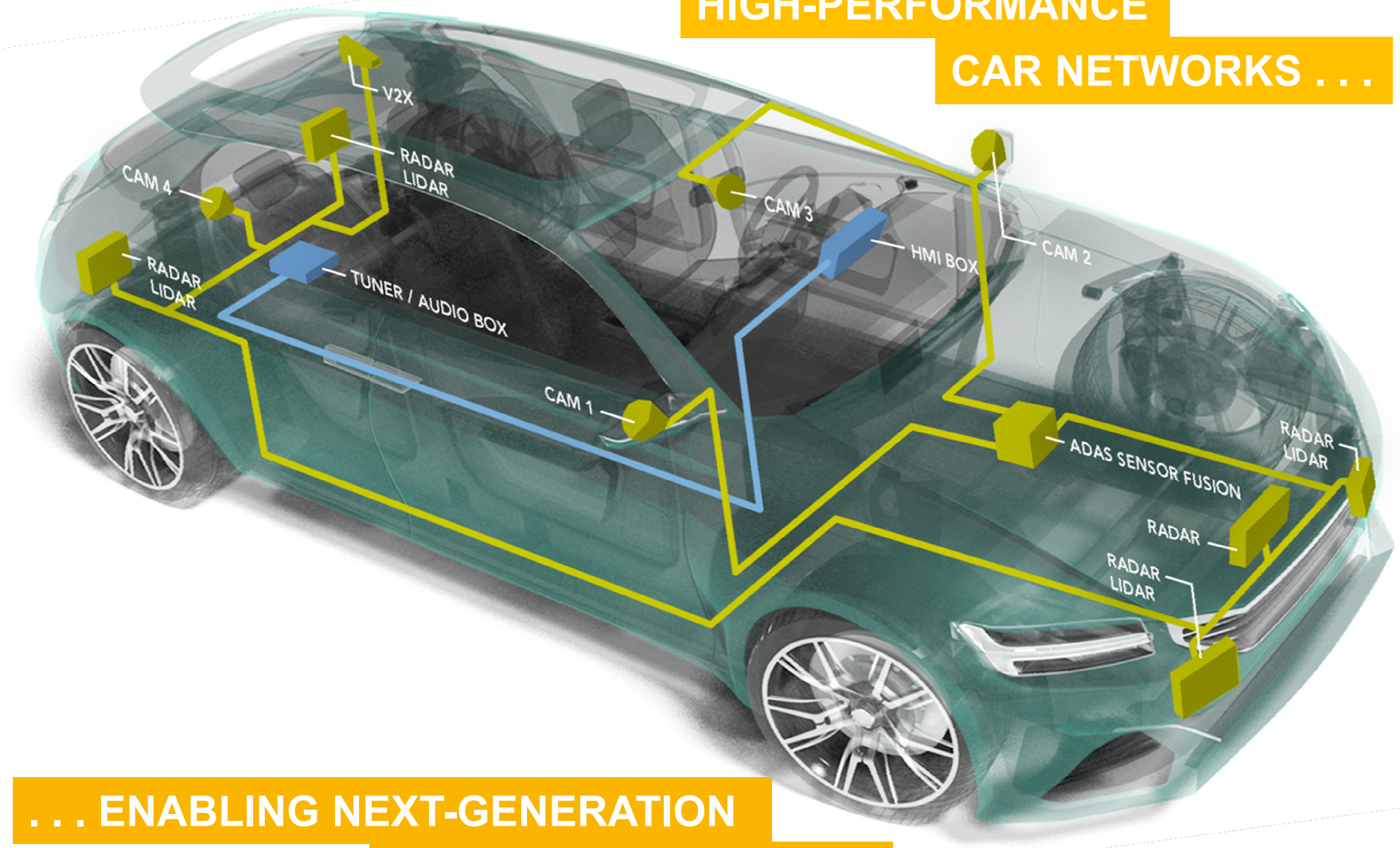
AN INDICATOR FOR FUNCTIONAL SAFETY

Airbags	20,807,538
Ignition keys/switches	16,299,079
Electrical/Electronics	4,964,662
Brakes	4,754,297
Powertrains	3,882,814
Steering	2.552,484
Fuel Systems, leaks	2,050,443
Suspension	1,697,464
Seatbelts	1,631,278
Seats (including child-seat latches)	1,253,729
Engine and Cooling	1.054,061
Tires, Tire-pressure-systems, Wheels	617.223
Accessoires and Labels	153,737
Throttle	19,202



Source: National Highway Traffic Safety Administration

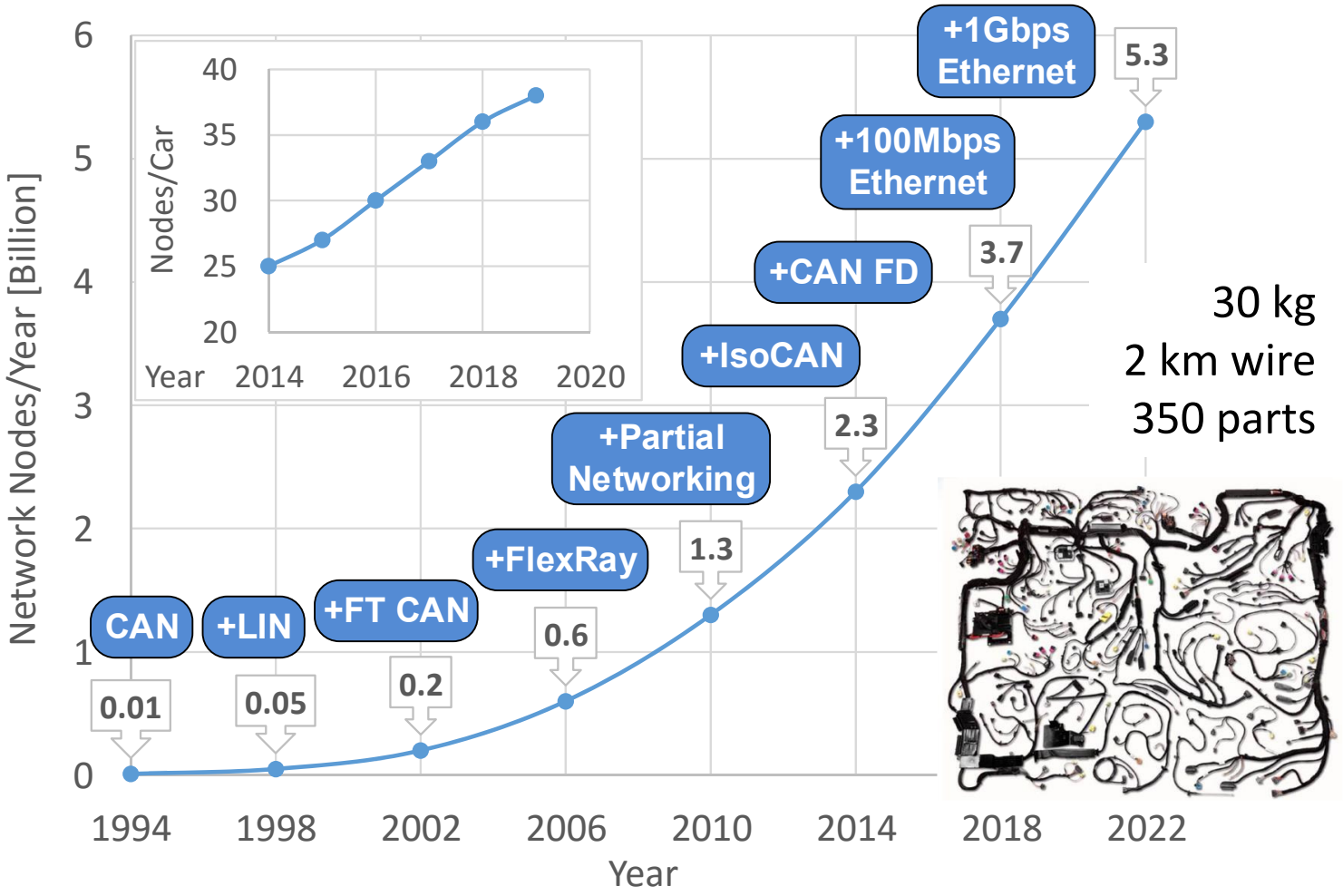
HIGH-PERFORMANCE CAR NETWORKS . . .

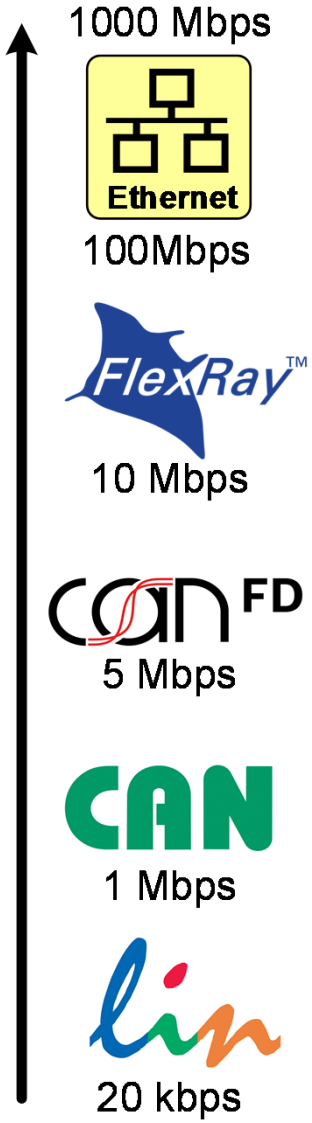


. . . ENABLING NEXT-GENERATION SYSTEM PARTITIONING

IN-VEHICLE NETWORKS

MORE CONNECTIONS – MORE BANDWIDTH

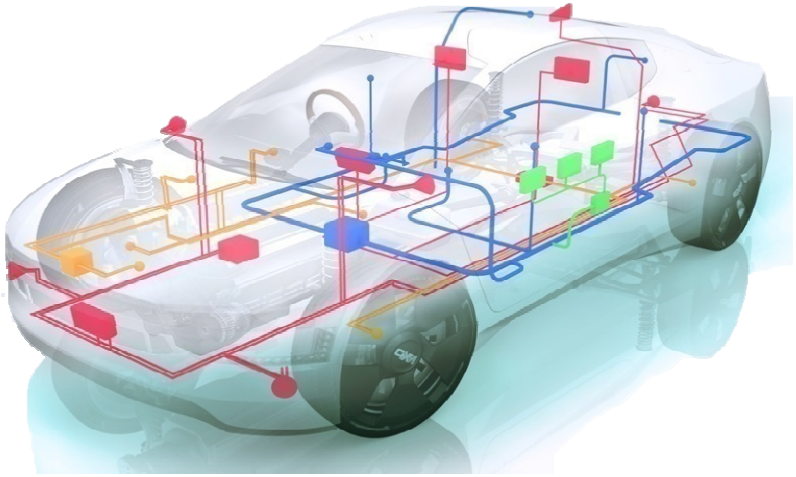




AUTOMOTIVE ETHERNET

TRUE AUTOMOTIVE PHY

- 100BASE-T1 = 100Mb/s Full-Duplex
- EMC and ESD (HBM, IEC61000-4-2)
- Transient pulses (ISO7637)
- Extensive diagnostics, fail-safe behavior
- Temperature range: -40 to +125 °C



- Reliable, cost-effective, compact
- Low power sleep & standby modes
- Robust remote wake-up (Partial Networking)
- Standardized, scalable
- 100Mbits/s today, 1Gbit/s tomorrow

Unshielded Twisted Pair Cable:
30% less weight

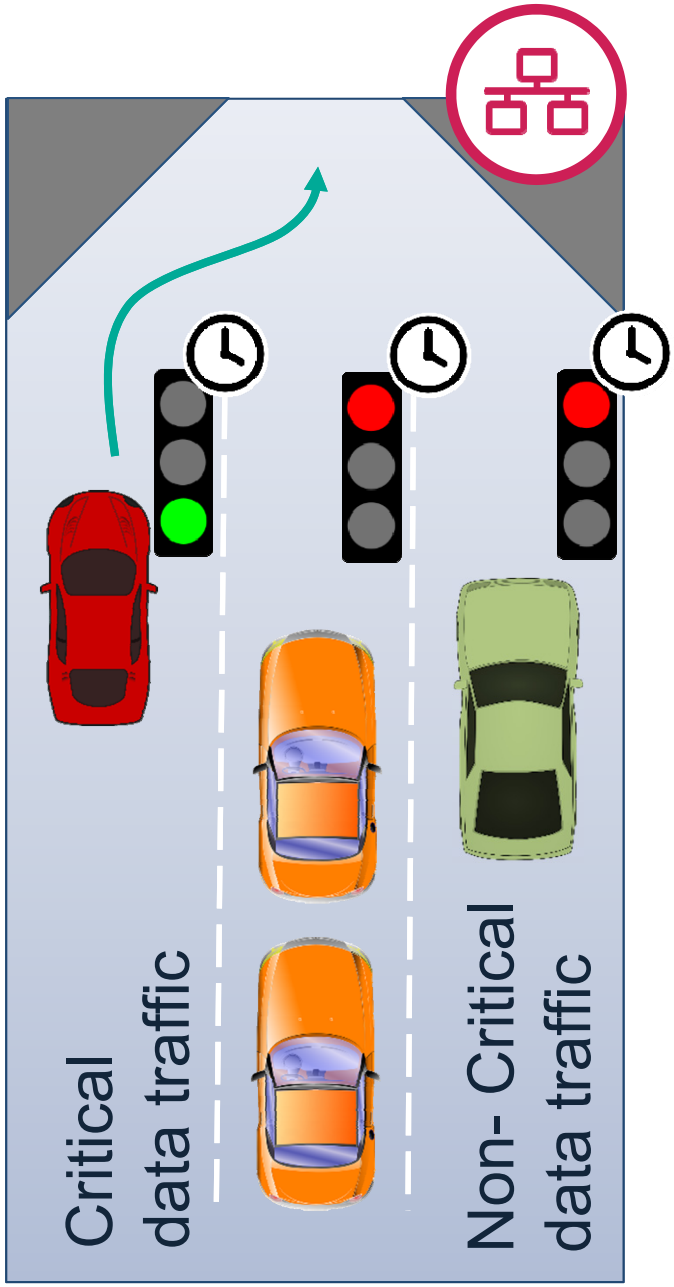
OPEN ALLIANCE

AUTOMOTIVE ETHERNET

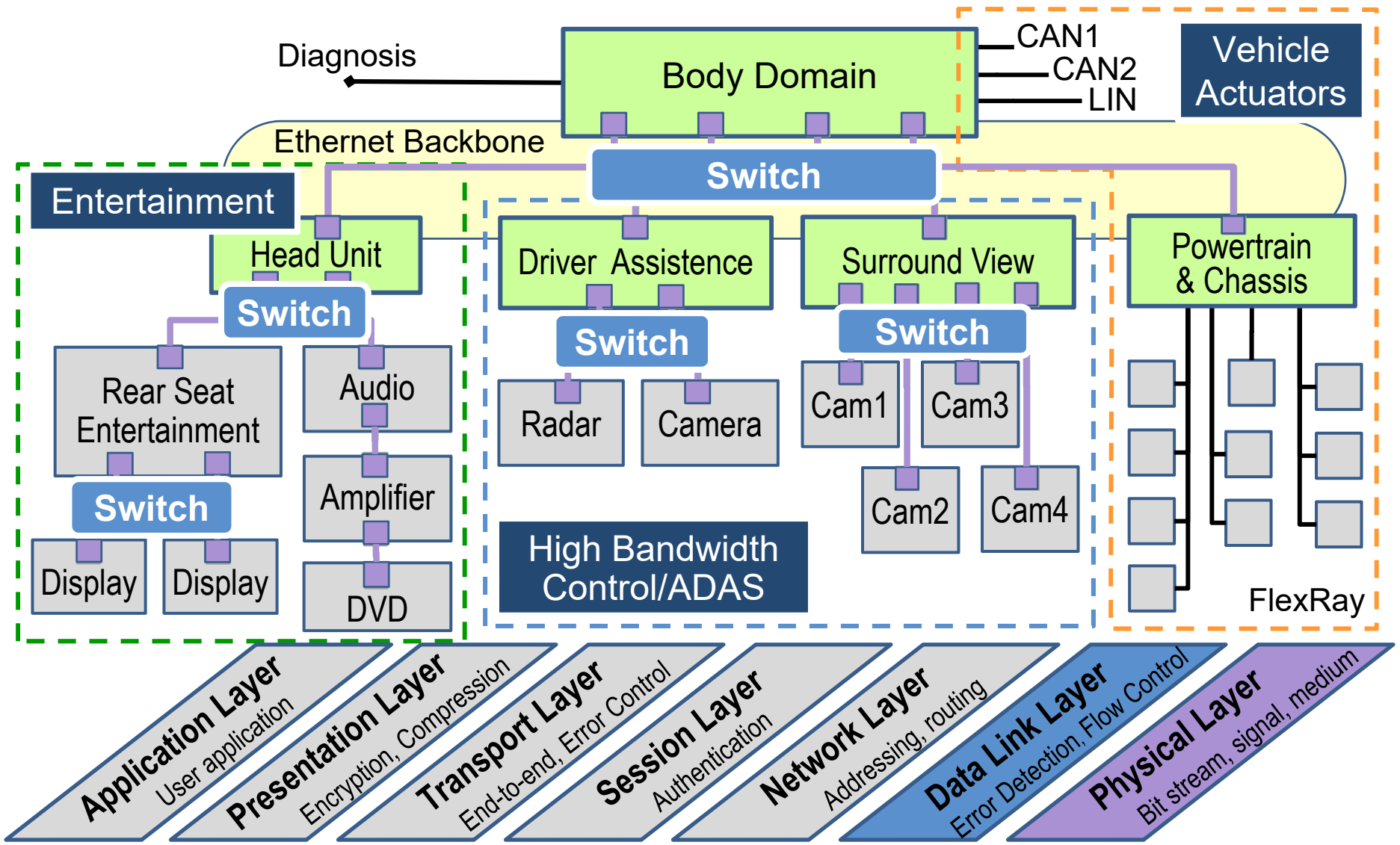
DETERMINISTIC

- Vital for Self-Driving: defined latencies
- Important for Multimedia: audio in sync with video

- Prevents slowing down critical data by less critical one
- Enables to define precise network delays for critical data
- Enable combined transmission of critical and non-critical traffic on the same network

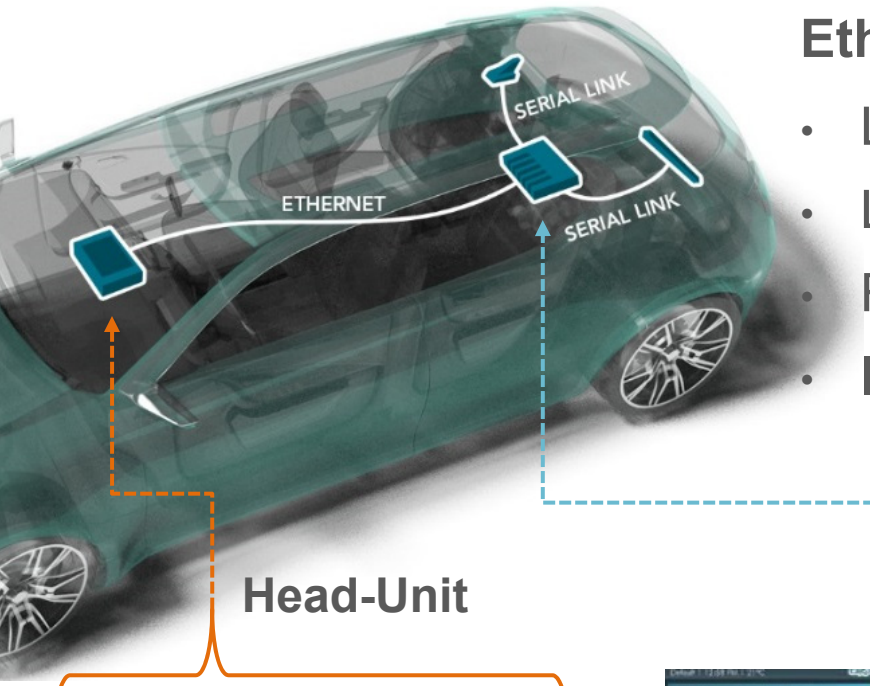


THE NETWORK OF THE FUTURE CAR
2020: DOMAIN-BASED NETWORK



THE NETWORK OF THE FUTURE CAR

DISTRIBUTED ARCHITECTURE



Ethernet enables Distributed Architectures:

- Life-Cycle separation (consumer vs vehicle)
- Lower costs for R&D and manufacturing
- Reduced cable cost / weight
- Improved broadcast reception performance

Head-Unit

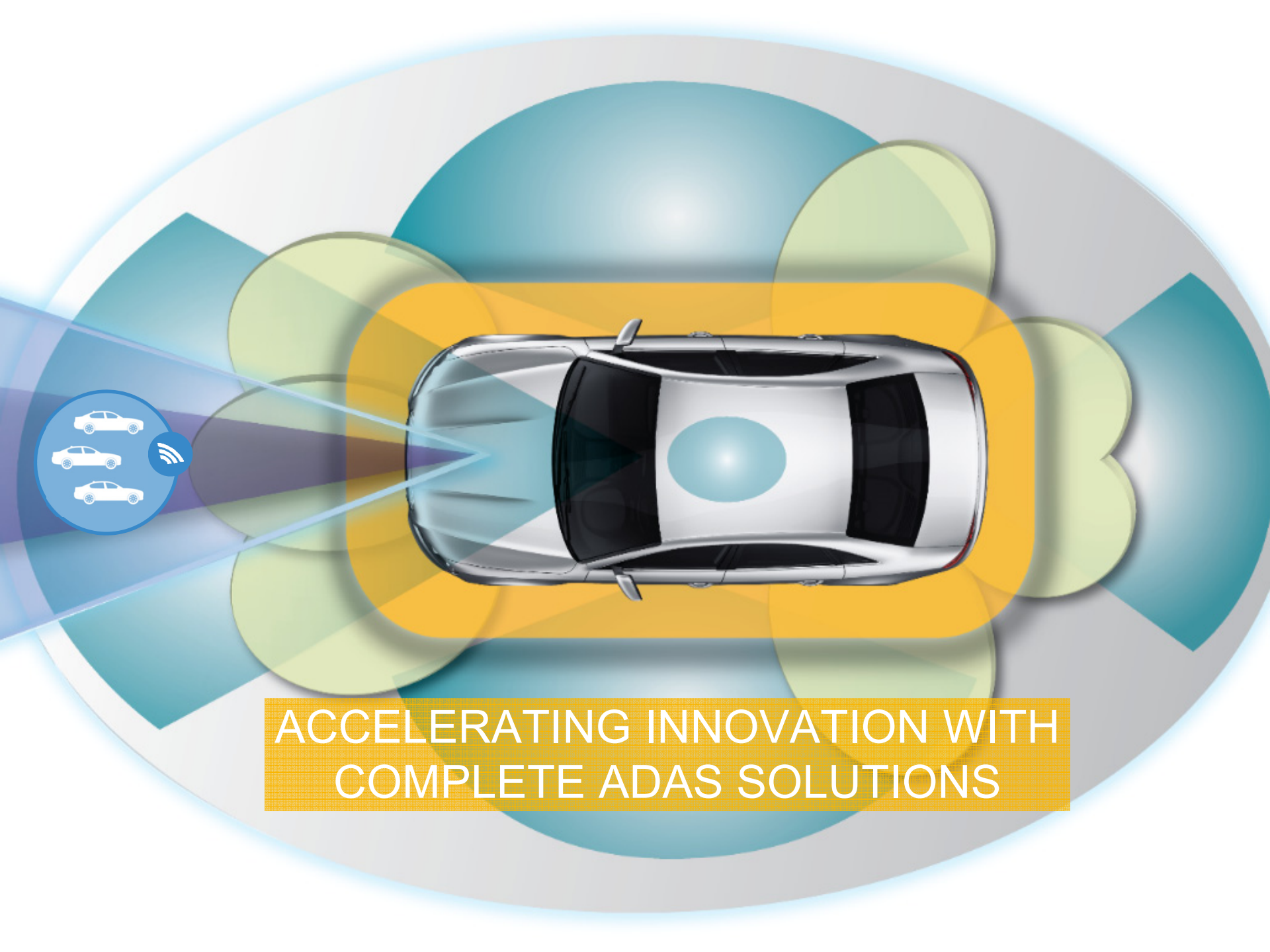
Navigation	HMI & Vehicle Control	Phone Connectivity
CD/DVD/ SD/HDD	Multimedia Playback	Internet

Satellite Antennas Radio & Amplifier Box

Sound Equalizer	Power Supply	SiriusXM	DAB / HD / DRM
Noise Cancellation	Amplifier	TV	AM/FM

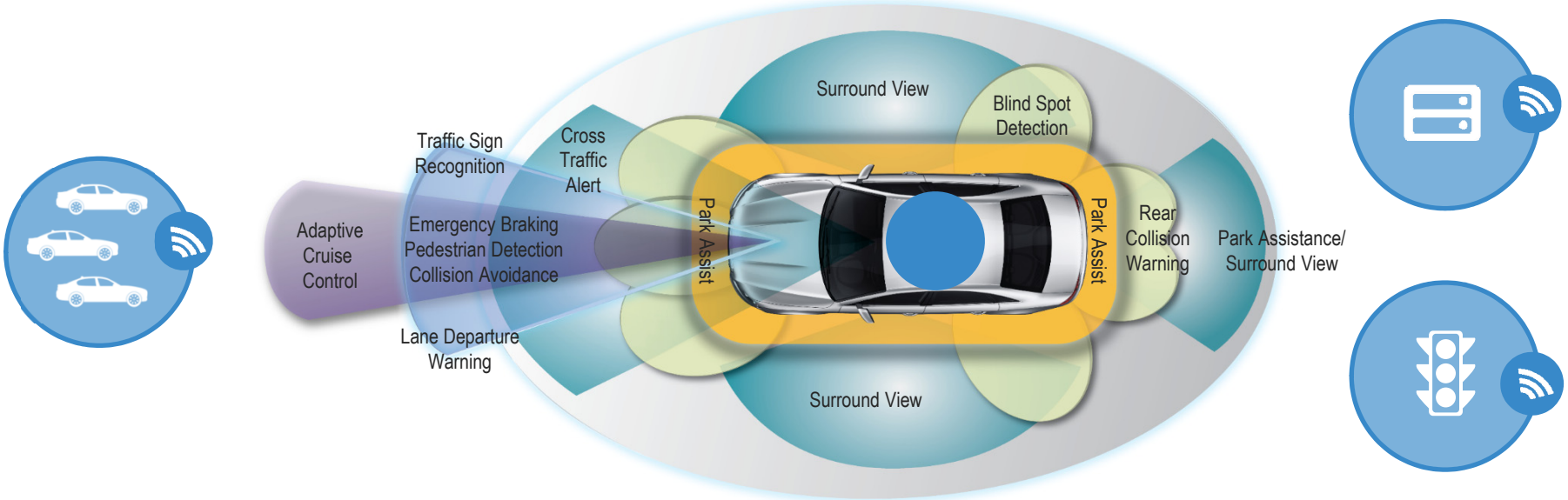
- Consumer-driven
- Car & electronics loosely coupled
- Shorter life-cycle

- Vehicle specific components
- Car & electronics tightly coupled
- Long life-cycle


ACCELERATING INNOVATION WITH
COMPLETE ADAS SOLUTIONS

ENABLING THE SECURE CONNECTED CAR OF TOMORROW

Significantly reducing the >1.3M global road fatalities

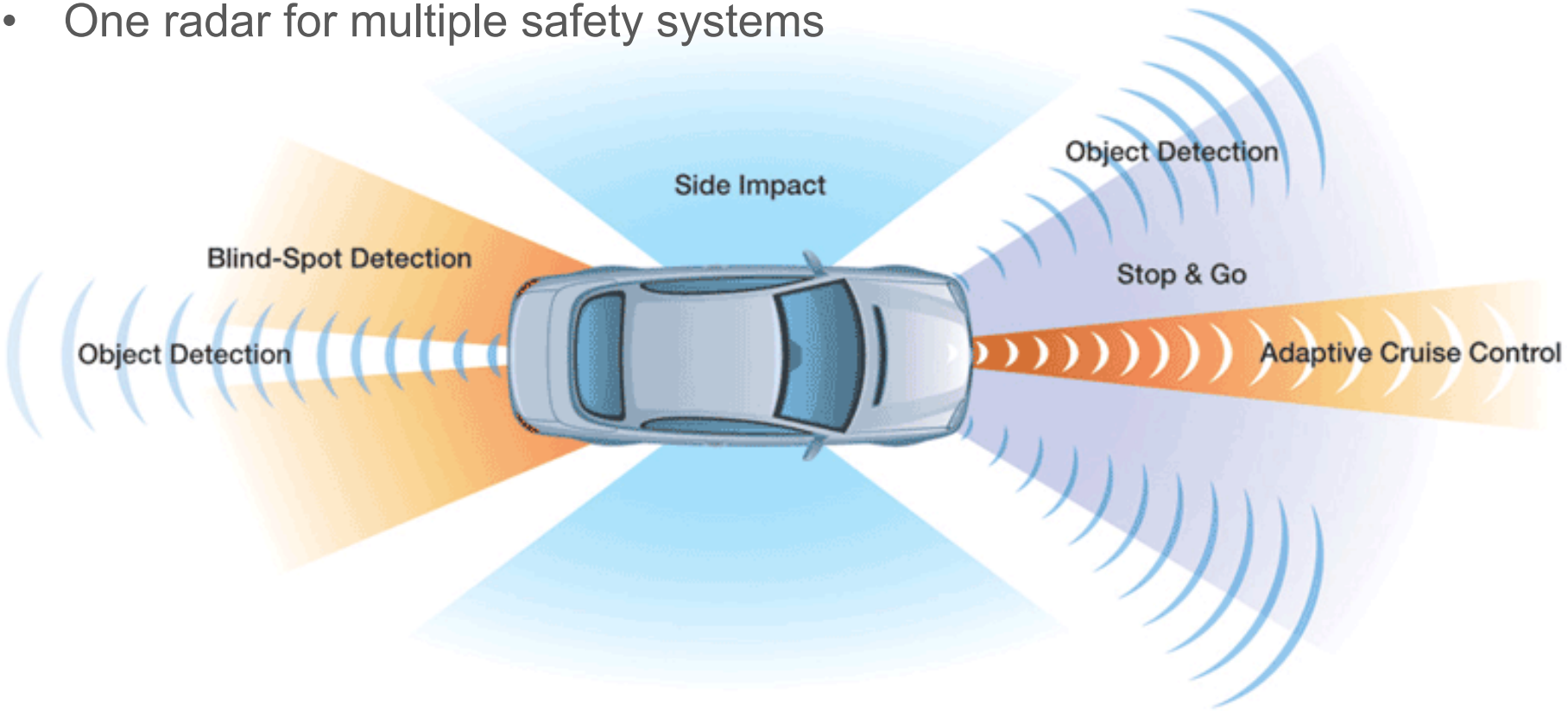


SENSE	Secure Network	THINK	Secure Network	ACT	BIG DATA
Radar Vision Secure V2X		Processing Sensor Fusion Security		Powertrain Chassis Braking	Digital Networking Infrastructure Security

CAR RADAR

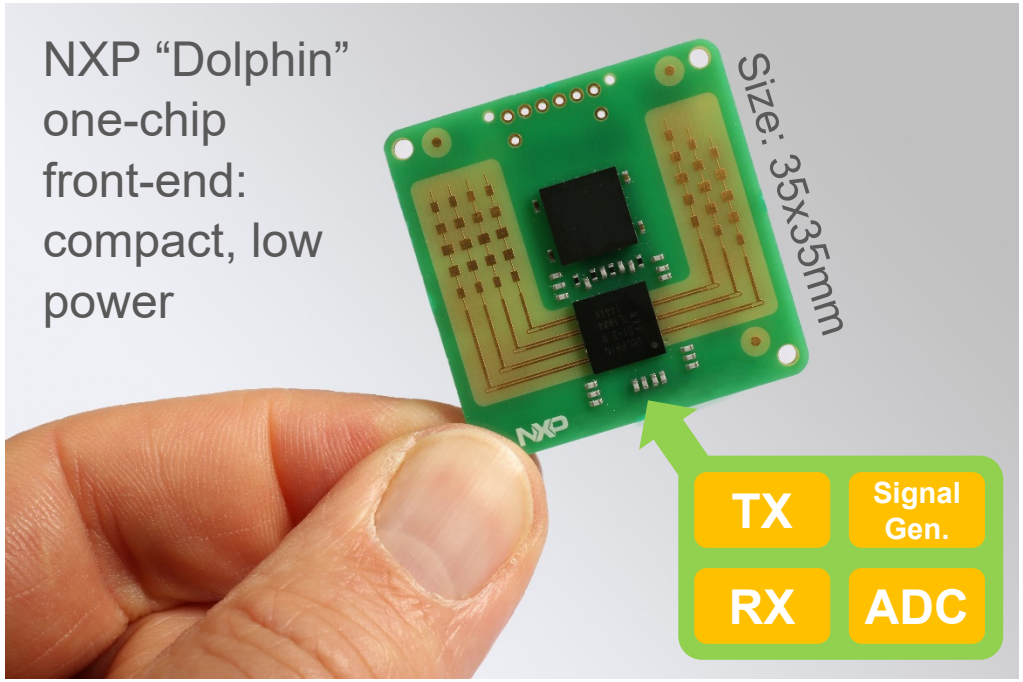
77 – 81 GHZ

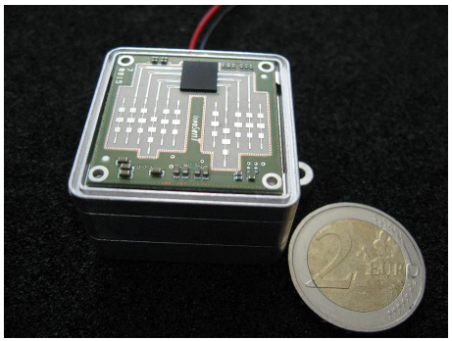
- Precise range, approach speed and angle data
- Short-, mid- and long-range functionality
- Excellent multi-target discrimination
- One radar for multiple safety systems



CAR RADAR

RFCMOS: SYSTEM SIZE OF A STAMP





CMOS is the next big step:

- Cocoons of radar sensors for 360° surround view
- Driving radar-based safety from premium into volume market
- Making ultra-sonic parking sensors obsolete
- Next gen: RFCMOS allows integration of frontend with DSP & µC

VEHICLE-TO-EVERYTHING (V2X)

COMMUNICATIONS BASED ON IEEE802.11P STANDARD

INTELLIGENT TRANSPORT SYSTEMS (ITS)

Avoiding road accidents

Improving traffic flow / CO_2

Enabling autonomous driving

IEEE802.11p is derived from IEEE802.11a/g (today's WiFi standard in computing)

VEHICLE-TO-EVERYTHING

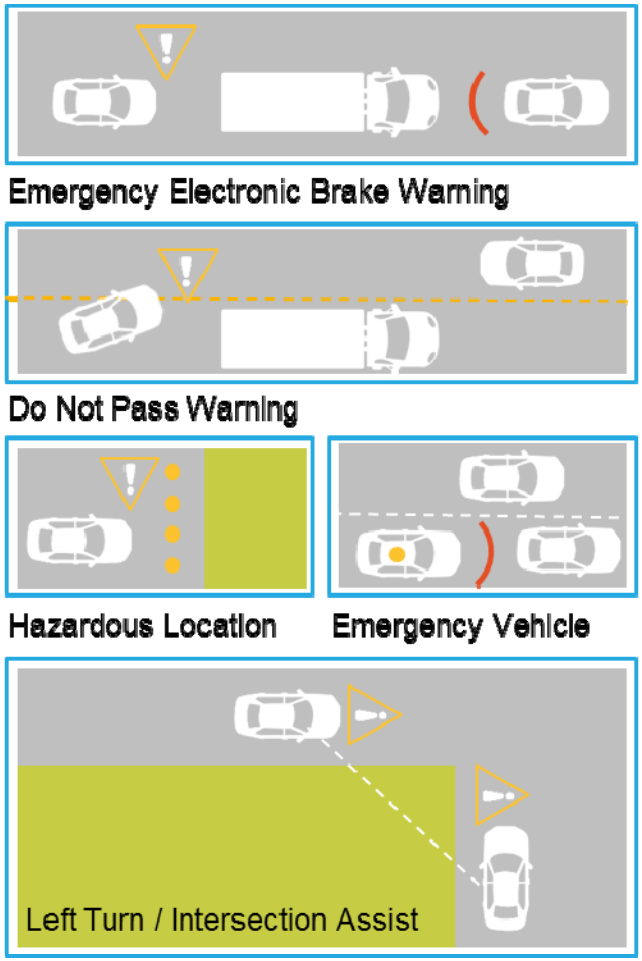
USE CASE EXAMPLES

Typical V2V

- Hazardous location warning
- Slow vehicle warning
- Stationary vehicle warning
- Emergency brake light
- Emergency vehicle warning
- Motorcycle approaching indication

Typical V2I / I2V

- Probe Vehicle (Floating Car) Data
- Signal traffic light phase and time
- Road works warning
- In-vehicle signage

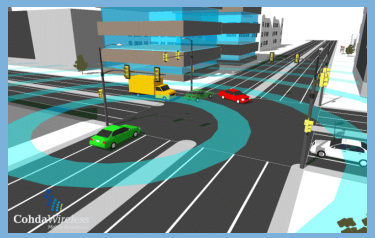


SECURING V2X COMMUNICATIONS

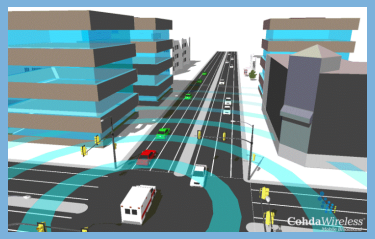
SECURITY

WAS THE MESSAGE NOT MODIFIED?
DID IT REALLY ORIGINATE FROM CAR A?
CAN I TRUST CAR A?

CAR AND MESSAGE AUTHENTICATION REQUIRED TO PREVENT TRAFFIC DISRUPTION OR IMPERSONATION



Seeing around corners

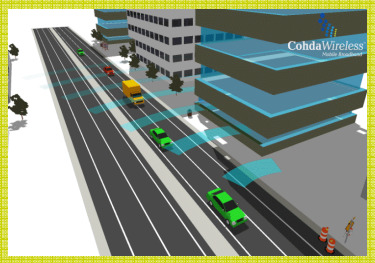


Emergency Vehicle Warning

PRIVACY:

CAN OTHERS TRACK ME WHILE DRIVING?

HIGH DEGREE OF ANONYMITY (IDENTITY HIDING) REQUIRED TO PREVENT TRACKING

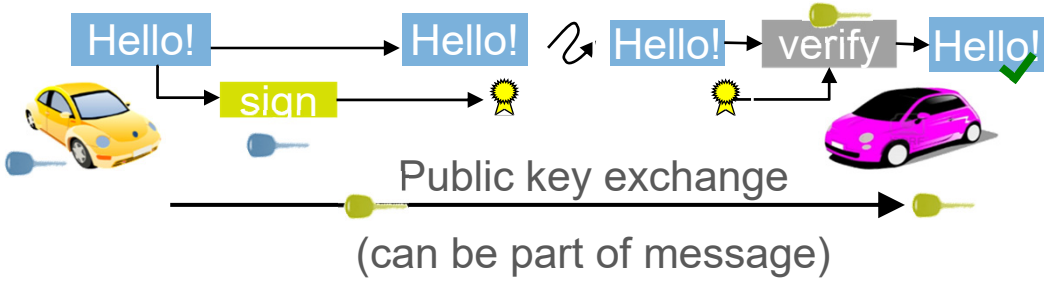


Hazard Warning

SECURING V2X COMMUNICATIONS

MESSAGE AUTHENTICATION VIA DIGITAL SIGNATURES

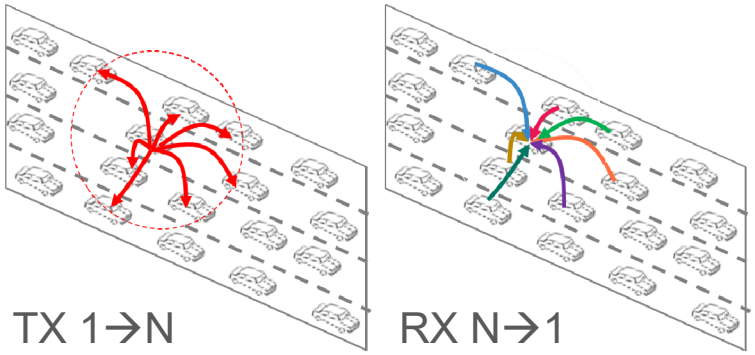
Authentication via digital signature



Based on

Hash function → unique identifier for message

Public-key crypto - two keys (private/ public)



IEEE (US) & ETSI (EU) standards mandate Elliptic Curve Digital Signature Algorithm

RSA signatures too long

Comparable security strength of

RSA3072b ~ ECC256b ~ AES128b

	TX	RX
Operation	Signature generation	Signature verification
Rate	Low: ≤ 20 / s	**High: 400-1000 / s**
Security level	**High: protection of private keys (car identity)**	Modest: only non-secret data

PEOPLE MUST BE ABLE TO TRUST THEIR CARS

Beckstrom's* Laws of Cyber Security

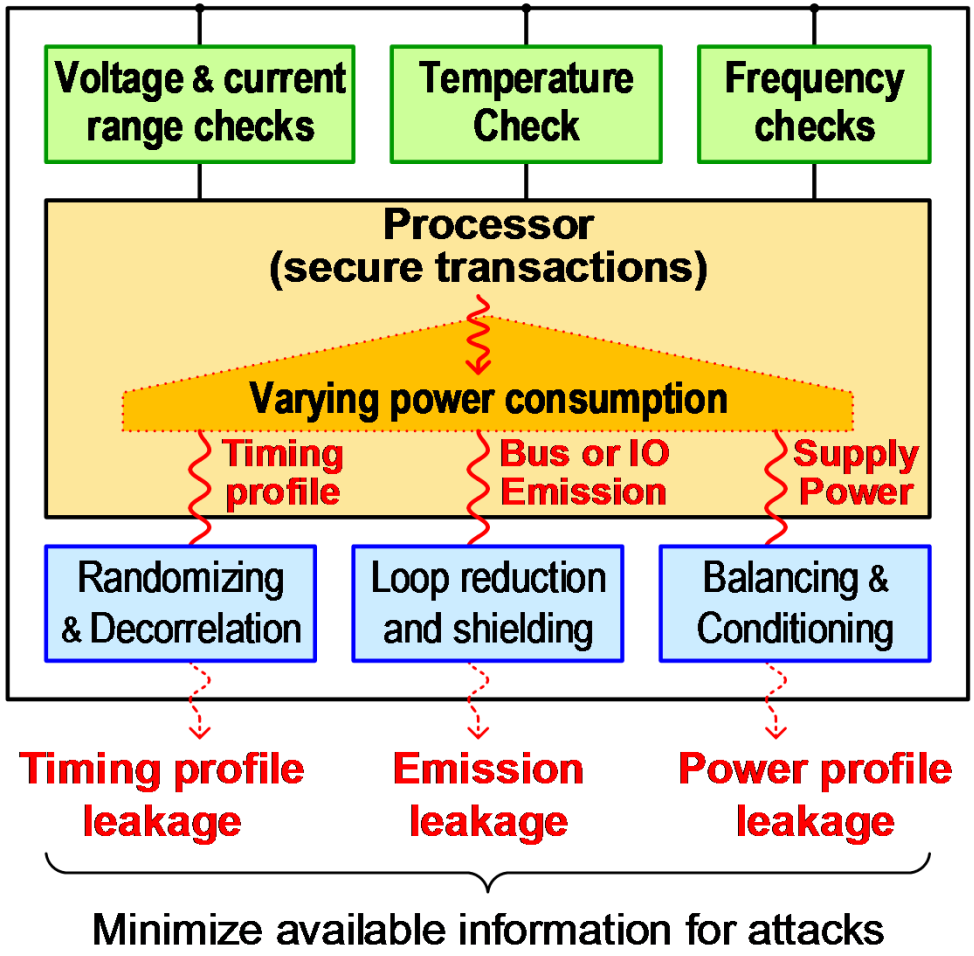
1. Everything that is connected to the Internet can be hacked
2. Everything is being connected to the Internet
3. Everything else follows from the first two laws

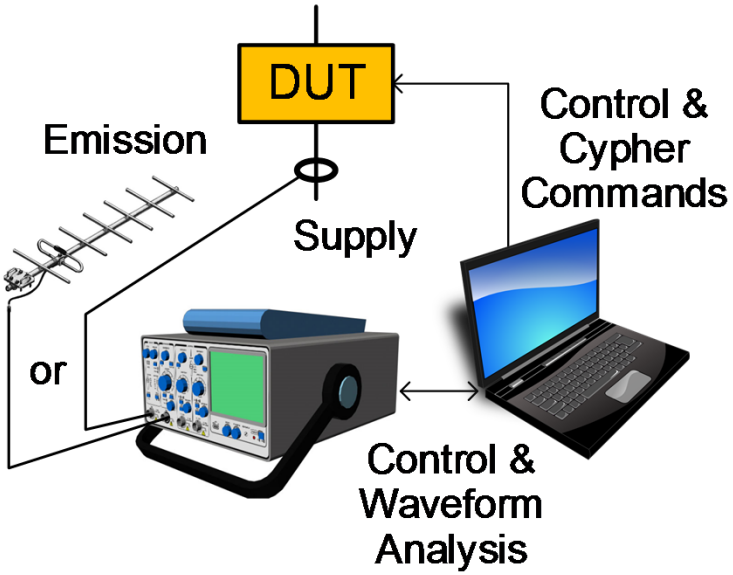
*Rod Beckstrom, CEO and President of ICANN, former Director of the National Cyber Security Center

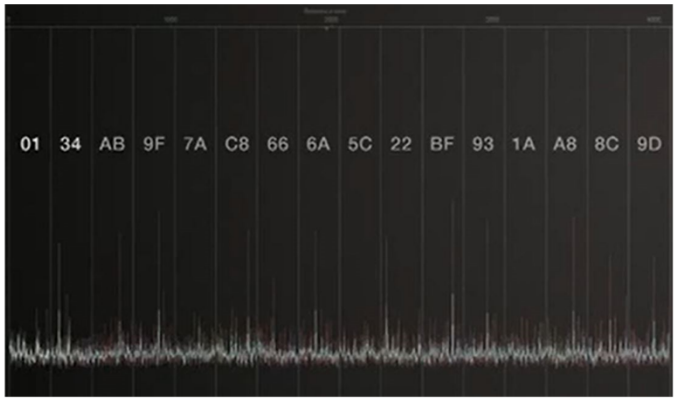
PHYSICAL IC ATTACKS ENABLE REMOTE HACKS
SECRET KEYS ARE RETRIEVED FROM DEVICE

Invasive Attacks	Semi-Invasive Attacks Fault Attacks	Non-Invasive Attacks Leakage
Reverse Engineering Delayering 	Global & Local Light Attacks	Photo emission Analysis
Micro-probing Forcing Manipulation 	Spike/Glitch injection	EMA Analysis
Electron Microscopy/ Atomic Force Microscopy	Alpha Particle Penetration	Timing Analysis
Contrast Etching Decoration		SPA/DPA Analysis

PHYSICAL ATTACKS AND HARDWARE PROTECTION



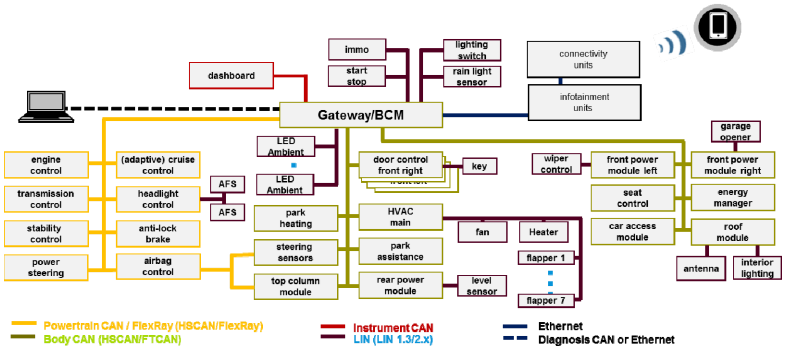




SYSTEM SECURITY
FOR IN-VEHICLE NETWORKS

- Traditional car network architectures offer limited protection levels

- Increasing connectivity makes these cars very vulnerable



- Automotive Security must be an integral part of the car's design & lifecycle
  - Security-by-design
  - Privacy-by-design
  - Impacting in-vehicle electronics architecture

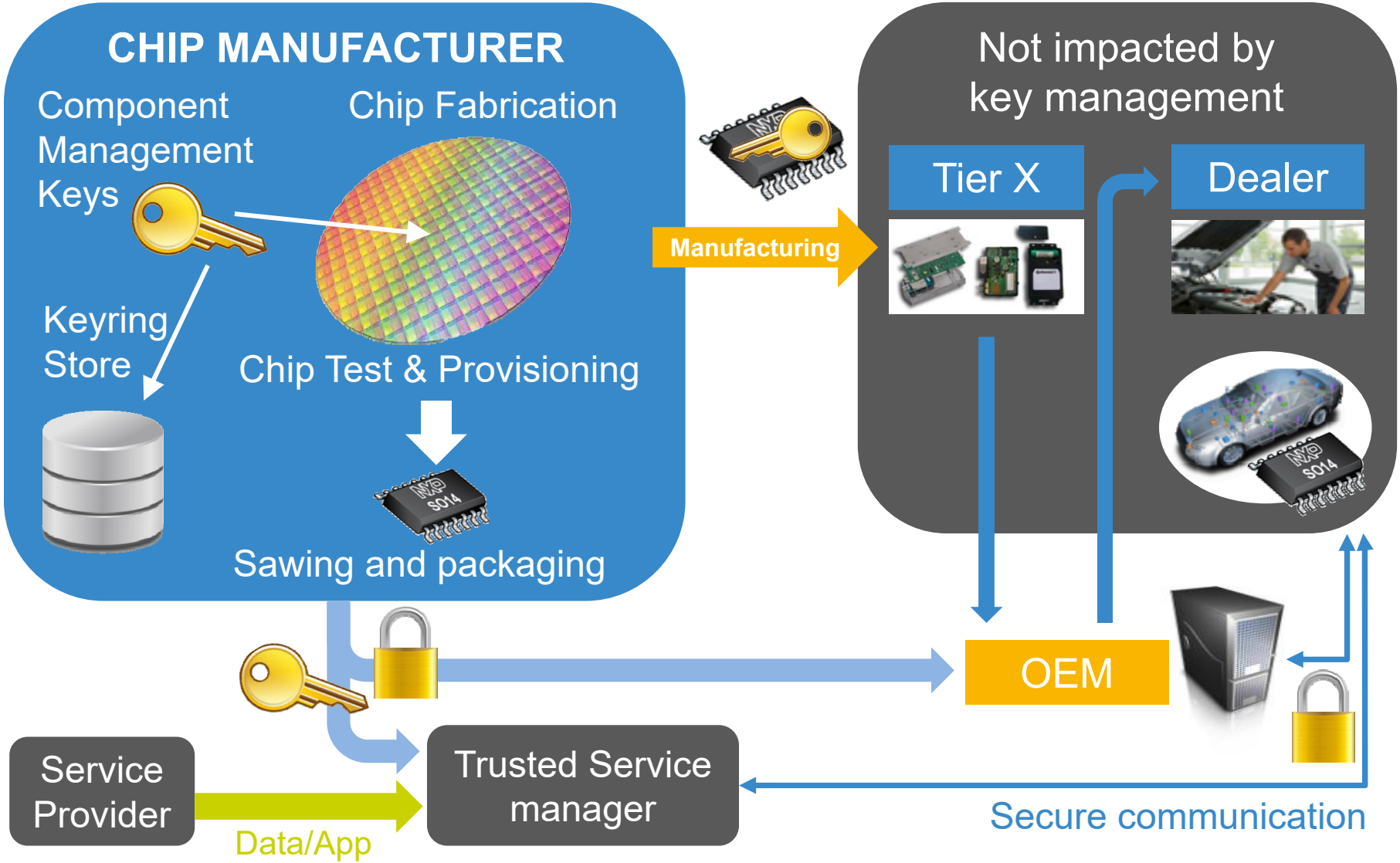
1 WIRELESS CONNECTIONS BASED ON SECURE ELEMENTS

2 SECURE APPLICATION PROCESSING

3 SECURE NETWORKING

SYSTEM SECURITY

REQUIRES RELIABLE TRUST PROVISIONING



SUMMARY

Consumers need to be able to trust their cars

– Quality, Safety & Security are basic requirements

Key technologies to make self-driving, securely connected cars a reality

– Compact radar solutions based on mixed-signal RFCMOS

– Secure, high-performance V2X

– High-bandwidth distributed vehicle networks / Ethernet

– Cryptoelectronics

No need to reinvent the wheel … but to ADAPT what we already know from other industries

http://www.nxp.com/video/the-car-of-the-future-powered-by-nxp:NXP-CAR-OF-THE-FUTURE


THE ROAD AHEAD FOR
SECURELY CONNECTED CARS
THANK YOU
NXP
SECURE CONNECTIONS
FOR A SMARTER WORLD